A.4.3

INTEROFFICE COMMUNICATION

TO:	Tom Crepeau, DHWM, CO
FROM:	John Palmer, DHWM, NEDO, through Harry Courtright, DHWM, NEDO
SUBJECT:	Closure Certification for Amsted Industries, Incorporated's (d.b.a. American Steel Foundries) Hazardous Waste Drum Storage Areas 'A' and 'B'. (OHD 981 090 418)
DATE:	November 4, 1997

On June 13, 1995, I conducted a post closure certification inspection for two former hazardous waste drum storage areas, located at Amsted Industries, Incorporated's (d.b.a. American Steel Foundries), 1001 East Broadway Street, Alliance, Ohio. At the time of the inspection, the units appeared to be free of any residual waste. To the best of my ability to determine from a visual examination, and based on information submitted with the certification received at this office on September 27, 1995 and October 30, 1997, contamination associated with the unit appears to have been remediated to a point protective of human health and the environment.

To the best of my knowledge, the closure was conducted in accordance with the approved closure plan (Approval date: January 23, 1997) and all applicable hazardous waste regulations. The closure certification was prepared by Dames and Moore, Incorporated, and certified by Joseph B. Suhre, P.E. (for Dames and Moore, Inc.), and John Oesch, Plant Manager of American Steel Foundries. The certification contained the correct wording as specified in OAC Rule 3745-50-42 (D). Laboratory data documenting the removal and decontamination efforts were included in the approved closure plan and were reviewed by me.

The facility will revert to large quantity generator status, and is no longer subject to financial assurance requirements.

ENVIRONMENTAL MEASURES:

Approximately two fifty-five gallon drums of F001/ F002 contaminated soil were removed from the site and disposed of properly.

JP:cl

cc: Harry Courtright, DHWM, NEDO
Ahmed Hawari, DHWM, NEDO
Linda Neumann, DHWM, CO
Montee Suleiman, DHWM, CO
Harriet Croke, USEPA Region V

CLOSURE CERTIFICATION REPORT
FOR
ELECTRIC ARC FURNACE BAGHOUSE
HAZARDOUS WASTE MANAGEMENT UNIT

Prepared for:
AMERICAN STEEL FOUNDRIES
ALLIANCE, OHIO

Prepared by:
RMT, Inc.
Dublin, Ohio

April 1995

STATE OF OHIO
ROBERT J.
VETTER
54849
Madison,
WI
PROFESSIONAL REGISTERED

3/31/95
Robert J. Vetter

Robert J. Vetter, P.E.
Vice President, Northern Region
Technical Operations Director

Donna I. Williamson

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Project Hydrogeologist

Craig S Schmeisser

Craig Schmeisser
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2169.33:MH:RPT:asf0224

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EXECUTIVE SUMMARY AND CERTIFICATION STATEMENT

Amsted Industries, Inc., d.b.a. American Steel Foundries (ASF) owns and operates an electric arc furnace (EAF) to produce steel castings. The EAF generates a baghouse dust which may have lead and cadmium concentrations in excess of regulatory limits for hazardous waste. The EAF has been in operation for over 20 years, and soils testing beneath the baghouse indicated potentially elevated levels of cadmium, chromium and lead.

In response to a December 1, 1992 Consent Decree from the Ohio EPA, ASF prepared a Closure Plan (January 1993, rev. September 1994) to address closure of the area beneath the baghouse as a RCRA unit. In accordance with this Closure Plan, ASF initiated closure activities in 1993 and completed removal of contaminated soils in August 1994.

In general, closure activities included sampling and analysis of background soils to establish upper confidence limits (UCLs), excavation and off-site disposal of soils beneath and directly adjacent to the baghouse, collecting and analyzing soils during and following excavation activities, backfilling with clean soils and covering the area with a concrete surface. Decontamination of equipment and proper disposal of residuals was also included during closure activities.

To evaluate the potential impact of the site on underlying soils, 12 background samples were collected and analyzed for total barium, cadmium, chromium and lead. UCLs were statistically established for each metal based on these results. 85 samples were collected from the excavated area, 42 following the first round of excavation and another 43 following final excavation of the area. The total metals concentrations for these confirmatory samples were compared to the UCLs. After final excavation, barium and lead were below the UCLs for over 95% of the second round samples.

Although cadmium and chromium exceedances were less frequent for the second round of samples, they occurred in 40 to 50% of these samples. However, these exceedances were at much lower concentrations than those found in the first round samples. Because excavation had reached the top of the concrete footings of the baghouse, ASF determined that the integrity of the baghouse structure could be compromised by further excavation. To confirm the relatively low concentrations above background levels for soils in the bottom of the excavation, one sample was pulled from the center of the excavation, two feet below the surface. Results indicated that only cadmium exceeded the UCL

(1.7 mg/kg compared to a UCL of 1.0 mg/kg). At that point, the excavation was filled with clean compacted soil and covered with concrete. Based on the fact that soils left in place had relatively low concentrations above background levels, no saturated conditions were encountered during the excavation, and a concrete pad now covers the excavated area, the final status of this area will be protective of human health and the environment and has met the following objectives:

- Minimizes the need for further maintenance; and
- Controls, minimizes, or eliminates to the extent necessary to protect human health and the environment, post-closure escape of hazardous wastes, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the groundwater, or surface water, or the atmosphere.

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

Robert J. Vetter

Robert J. Vetter, P.E.
RMT, Inc.
Technical Operations Director, Northern Region

John Oesch
American Steel Foundries
Plant Manager

Section 1
INTRODUCTION

1.1 Background

Amsted Industries, Inc., d.b.a. American Steel Foundries (ASF) owns and operates an electric arc furnace (EAF) used to produce steel castings at the Broadway Street facility in Alliance, Ohio. In order to produce the steel castings, scrap metal is melted in the EAF to supply the molten metal necessary to produce the castings. During these melting operations, particulate emissions are generated and captured in a Pangborn baghouse which is connected to the existing furnace through enclosed ductwork. ASF's EAF dust samples, tested by TCLP protocol, show lead and cadmium concentrations at levels higher than the regulatory limits (5.0 mg/L and 1.0 mg/L, respectively). Over the course of 20 years of operation, some spillage of dust may have occurred to the soils beneath the baghouse during routine practices of discharging the baghouse dust into appropriate shipment containers. In addition, ASF generates small quantities of wire welder dust which is characteristically hazardous for barium, and has been added to the EAF dust for disposal.

Preliminary testing of the soils beneath the baghouse for compositional metals showed potentially elevated levels of cadmium, lead and chromium. Barium was not included in this original testing, but was later identified as a potential constituent of concern. Due to the Consent Decree entered on December 1, 1992 involving ASF's landfill, the OEPA has ordered ASF to close the area beneath the baghouse which is classified as a Resource Conservation and Recovery Act (RCRA) unit. As a result of this decree, ASF is seeking closure of the area in accordance with applicable portions of the RCRA 40 CFR, Part 265, Subpart G, and Ohio Administrative Code (OAC) 3745-66.

1.2 Purpose and Scope

The purpose of this Closure Certification Report is to describe the closure activities that ASF has performed to close the area beneath the EAF baghouse.

The scope of this report includes the following:

- Description of the materials beneath the EAF baghouse.
- The construction methods used to remediate the materials beneath the EAF baghouse, including soil excavation and disposal.

- Analytical parameters and performance standards for determining clean closure, including the method used to establish background levels for hazardous constituents.

- The sampling plan used for the excavated soils beneath, and adjacent to the EAF baghouse.

- Estimated soil quantities excavated.

- Decontamination methods for the equipment used to handle contaminated material during closure.

- Results of confirmatory sampling analyses and comparison to previously established upper confidence limits.

- Documentation of closure activities.

This closure report is intended to fulfill the requirements applicable to the contaminated soils associated with the EAF baghouse dust, and to describe key activities, tests, and performance standards involved in closure of this waste management unit. These requirements are regulated under the applicable portions of 40 CFR Part 265, Subpart G, and OAC 3745-66.

Section 2

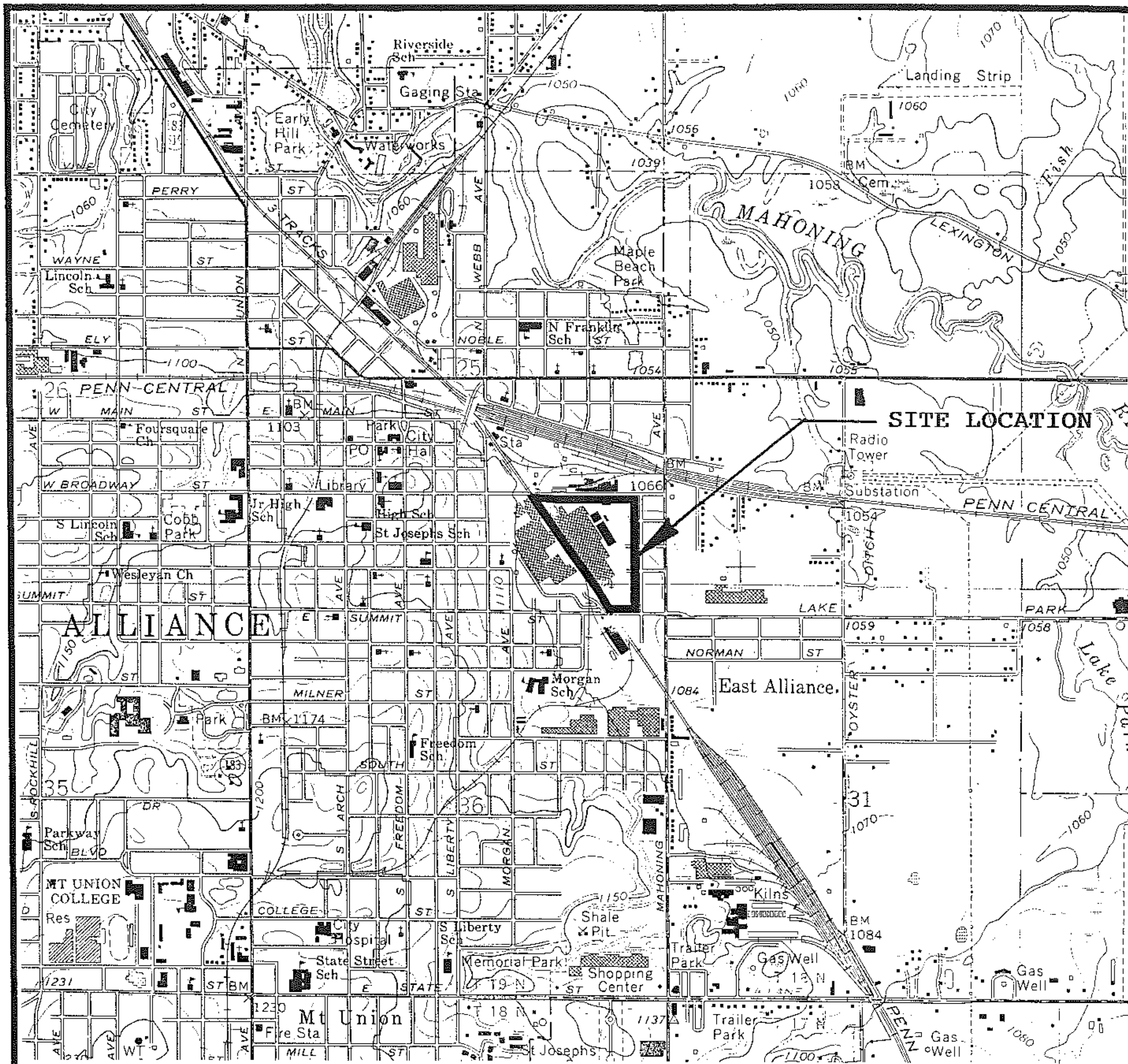
GENERAL FACILITY INFORMATION

2.1 Facility Name, Location, Contact and Standard Industrial Code

Name:	Amsted Industries, Inc. d.b.a American Steel Foundries Alliance Facility
Location:	1001 East Broadway Alliance, Stark County, Ohio
Contact:	Mr. Terry Bradway Environmental Manager American Steel Foundries 1001 East Broadway Alliance, Ohio 44601 (216) 823-6150 ext. 206
Standard Industrial Code:	3325
USEPA ID #:	OHD 981 090 418

2.2 Site Description

The Alliance Facility is located in the southeast quarter of Section 25, Township 29 north, Range 6 west in the City of Alliance, Ohio, in Stark County (see Figure 2-1). The EAF baghouse area is comprised of approximately 1320 square feet and is located in the northwest corner of the facility, approximately 2 feet west of the scrap metal storage building and 15 feet northeast of the truck scale as shown in Figure 2-2. The Pangborn baghouse receives particulate emissions, which are generated from melting scrap metal, using an EAF to supply the molten metal necessary to produce steel castings. Over the past 20 years, the possibility exists that spillage to the soils beneath the baghouse may have occurred during routine practices of discharging the baghouse dust from the collection hopper, in the bottom of the baghouse unit, to appropriate shipment containers.



STATE LOCATION

0 2000 4000

SCALE: 1" =2000'

SITE LOCATOR MAP
AMERICAN STEEL FOUNDRIES

SOURCE: BASE MAP FROM ALLIANCE, OH. 7.5 MINUTE USGS QUADRANGLE.

RMT INC.

DWN. BY: JEB	
APPROVED BY: DIW	
DATE: MARCH 1995	
PROJ.# 2169.33	
FILE # 21693302	

$$DWG$$
$$PRF$$
$$SCALE$$

FIGURE 2-1

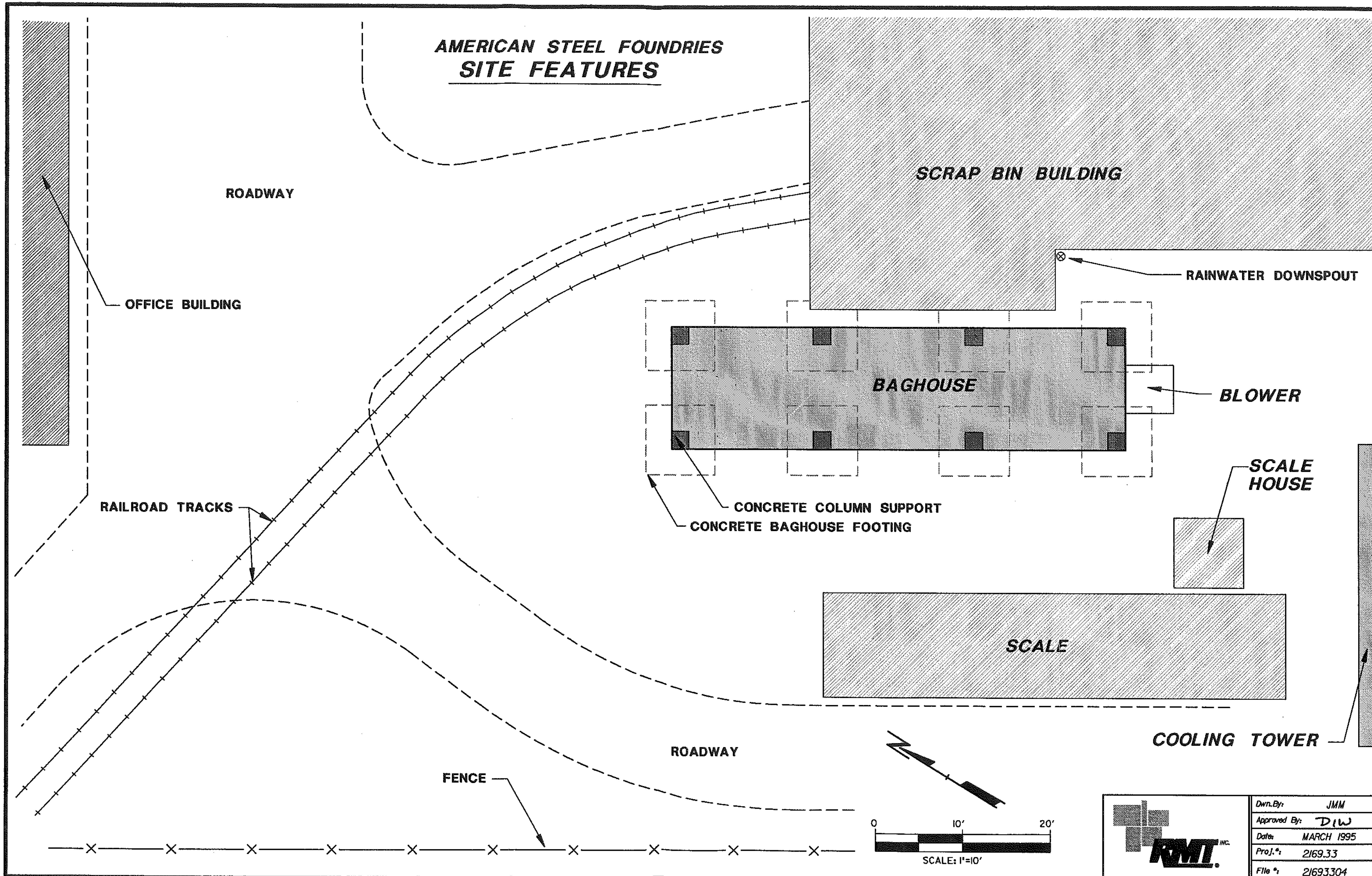

AMERICAN STEEL FOUNDRIES
SITE FEATURES
ROADWAY
OFFICE BUILDING
SCRAP BIN BUILDING
RAINWATER DOWNSPOUT
BAGHOUSE
BLOWER
SCALE HOUSE
CONCRETE COLUMN SUPPORT
CONCRETE BAGHOUSE FOOTING
RAILROAD TRACKS
SCALE
COOLING TOWER
ROADWAY
FENCE
0
10'
20'
SCALE: 1"=10'
RMT INC.
Dwn.By: JMM
Approved By: DIW
Date: MARCH 1995
Proj.#: 2169.33
File #: 21693304

FIGURE 2-2

2.3 Waste Characterization

The basis for classification of the EAF dust waste management unit as a characteristic hazardous waste is summarized in the following table:

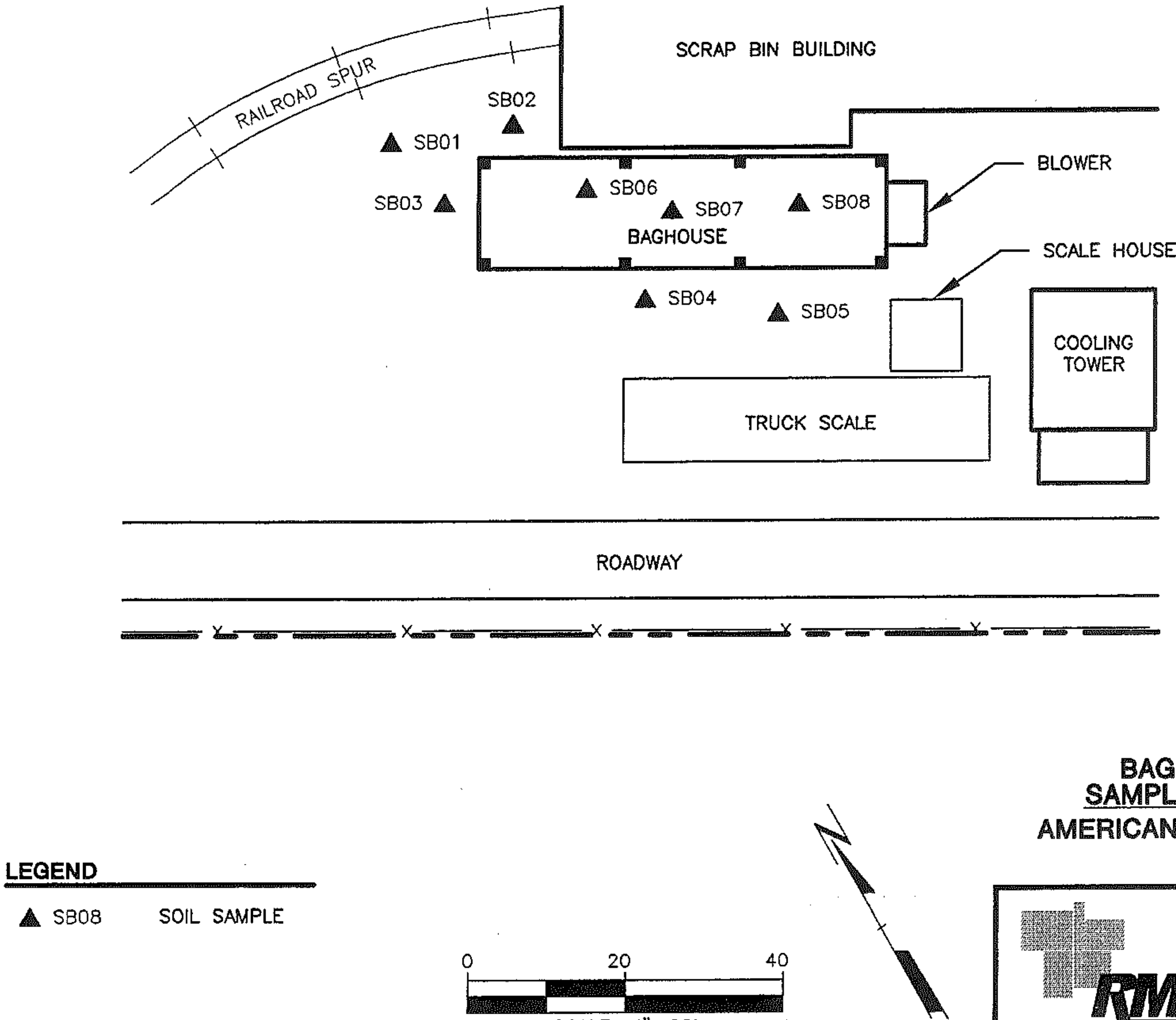
WASTE TYPE	HAZARDOUS CONSTITUENT	EPA HAZARDOUS WASTE NUMBER	MAXIMUM INVENTORY DUST	MAXIMUM INVENTORY HAZARDOUS CONSTITUENTS
Electric Arc Furnace Dust	Lead Cadmium	D008 D006	50,000 LBS.	500 LBS. 250 LBS.
Wire Welder Dust	Barium	D005	300 LBS.	Unknown

The EAF dust waste management unit was characterized by a Pre-Closure Sampling and Analysis Program for soils in the area of the baghouse and by previous baghouse area soil testing for total metals conducted by ASF. Information obtained from these studies was used to develop the closure approach presented in this document. Details of the Pre-Closure Sampling and Analysis Program are contained in Subsection 2.3.1.

2.3.1 Pre-Closure Sampling and Analysis Program

To obtain information regarding the extent of potentially elevated lead, cadmium and chromium concentrations in soils associated with the EAF dust waste management unit, ASF collected and analyzed 13 samples of underlying soils from the area of the EAF baghouse. Sampling activities were conducted on January 7, 1992. Barium analyses were not completed because barium had not yet been identified as a constituent of concern.

The general extent of hazardous materials in underlying soils above the upper confidence limits (UCLs) was determined based upon results of in-field work performed by ASF. During that time, 8 soil borings were installed in the area of the baghouse at the approximate locations shown in Figure 2-3. In addition to the 8 soil borings, 3 background samples were collected in areas not associated with baghouse activities as discussed in Section 3.3. From the 11 sample locations, 8 samples were collected at depths of 0 to 1 foot, 5 samples were collected at depths of 1 to 2 feet and 3 background samples were collected at depths of 0 to 0.5 feet below the surface. A physical description of the samples indicated that the material in the area of the baghouse consisted primarily of limestone, which ASF has used to build up road beds.



BAGHOUSE AREA
SAMPLING LOCATIONS
AMERICAN STEEL FOUNDRIES

RMT INC.	
	DWN. BY: JEB
	APPROVED BY: DIW
	DATE: MARCH 1995
	PROJ. # 2169.33
	FILE # 21693301

FIGURE 2-3

Of the 16 on-site samples collected, 13 were analyzed for cadmium, chromium and lead using compositional analyses, one was analyzed for cadmium and lead using TCLP analyses, and one was analyzed for chromium using TCLP analysis. Because previous full TCLP analyses (1991) and bench-scale testing indicated the EAF baghouse dust was hazardous due to the characteristics of only cadmium and lead, and because this waste was also listed due to the potential presence of chromium, no other constituents were investigated. As stated, barium was not addressed as a possible constituent of concern at that time. The analytical results are summarized in Table 2-1. The data contained in Table 2-1 indicated the following:

- Elevated concentrations of compositional cadmium, chromium and lead were observed in the underlying soils.
- TCLP results did not indicate the presence of underlying soil that is hazardous due to the characteristics of cadmium, chromium and lead.

From the boring logs and the analytical results, the vertical and horizontal extent of the wastes and underlying soils with concentrations above the UCLs was estimated. The Pre-Closure Sampling and Analysis Plan, soil boring logs, and the laboratory report sheets were included as appendices to the site Closure Plan.

TABLE 2-1
Pre-Closure Baghouse Area Soils Sampling and Analysis Results

ANALYTICAL PARAMETER	DETECTION LIMIT	SAMPLE LOCATION AND DEPTH																			HAZARDOUS WASTE LIMIT
		SB01		SB02		SB03		SB04		SB05		SB06		SB07		SB08		SB09	SB10	SB11	
		0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-1'	1'-2'	0'-0.5'	0'-0.5'	0'-0.5'	
Compositional Metals (mg/kg on a dry weight basis)																					
Cadmium	0.50	4.9	N/A	11	39	<1.1	N/A	7.7	9.8	<1.1	N/A	<1.1	<1.1	<1.1	<1.1	30	<1.1	<1.1	6.6	7.5	
Chromium	1.00	86	N/A	110	300	15	N/A	3000	1100	15	N/A	24	54	7.2	200	200	7.6	36	98	210	
Lead	10.00	190	N/A	390	1400	43	N/A	250	580	<22	N/A	44	190	<22	<22	1700	<22	55	460	420	
TCLP Metals (mg/L)																					
Cadmium	0.01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.62	N/A	N/A	N/A	N/A	1.0
Chromium	0.01	N/A	N/A	N/A	N/A	N/A	N/A	0.028	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.0
Lead	0.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.3	N/A	N/A	N/A	N/A	5.0

NOTES:

N/A Not analyzed

Sample locations SB09, SB10 and SB11 were collected for background determination, and were located outside of the Waste Management area.

Section 3
CLOSURE APPROACH

3.1 Objectives

ASF attempted to clean close the area beneath the EAF baghouse in accordance with 40 CFR 265.111 and OAC 3745-66-11. The regulations indicate that ASF must close the facility in a manner that

- Minimizes the need for further maintenance; and
- Controls, minimizes, or eliminates to the extent necessary to protect human health and the environment, post-closure escape of hazardous wastes, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the groundwater, or surface water, or the atmosphere.

To accomplish this, ASF used the closure approach described in Subsection 3.2. As discussed earlier, soil testing indicated that lead, cadmium, and chromium were present above levels of potential concern in the soils associated with the EAF dust waste management unit. Barium was later identified as a potential constituent of concern due to the practice of disposing wire welder dust at the unit. Previous characterization of the EAF baghouse dust only, indicated that the other TCLP metals were below regulatory criteria, and the TCLP organics were below detection limits.

3.2 Closure Approach

Based on the Pre-Closure Sampling and Analysis Program which was conducted by ASF as discussed in Subsection 2.3.1, closure activities at the site consisted of four major tasks:

- Excavation of soils with cadmium, chromium, barium, and lead levels significantly above the UCLs based on the site assessment.
- Conducting confirmatory soils sampling and analysis, and comparing the results to the UCLs.
- Placement of excavated material in the EAF for recycling, or disposal at an off-site approved hazardous waste facility.
- Backfill and compaction of the excavation with clean granular fill consisting of general fill and sand brought in from an off-site source.

During closure, materials which were determined to be associated with baghouse activities were excavated and placed into on-site Visqueen-lined roll-off boxes. Once the excavation was complete, the materials were either fed back into the EAF and recycled or disposed of at an approved hazardous waste facility. After excavation was complete, additional sampling was conducted as described in Section 5.

3.2.1 Excavation of Contaminated Material

The extent of contaminated materials was estimated as described in Subsection 2.3.1. Projected excavation depths based on these estimates and the structural integrity of the baghouse and building footings were determined to be two feet below grade in the front two-thirds of the baghouse, and no more than three feet in the back one-third of the baghouse. During excavation ASF used a phased approach to insure the structural integrity of the baghouse, including the following steps:

- excavating the soils beneath the baghouse to the originally projected depth, for one third of the area at a time;
- collecting verification samples following the initial excavation;
- repeating the above steps to the final excavation depth; and
- backfilling with clean granular soil as described in Section 4.5.

Verification samples were collected on the bottom and on the sides of the excavation. Side samples were taken toward the center and bottom of the sampling grid. The process described above was repeated for the second and third of the three areas under the baghouse.

3.2.2 Contaminated Materials Disposal

Contaminated materials were fed back into the EAF or disposed of off-site at an approved hazardous waste facility, as discussed in Section 4.4. Accumulated water from excavation and decontamination activities was collected and analyzed for later discharge to the POTW or for off-site treatment, if required, as detailed in Section 4.4.

3.2.3 Backfilling of Excavation

After excavation of the contaminated material was completed as described in Section 4, the unit was backfilled and graded. Backfill material consisted of clean granular material and general soils as needed from an off-site borrow source.

The fill materials were placed and compacted until the pre-excavation grades were achieved. The final grade promoted run-off and will blend with the surrounding terrain. The area was prepared to ensure that settlement and drainage was not a problem for the intended use of the area. Details are included in Section 4.5.

3.3 Determination of Upper Confidence Limits in Soils

Portions of the foundry, including the vicinity of the baghouse, were probably built on foundry sand and slag. Therefore, it was anticipated that foundry sand and slag would be encountered during excavation of soils beneath the baghouse. Since the purpose of the Closure Plan is to address the cleanup of wastes and residuals from the RCRA unit, it was necessary to differentiate between cadmium, chromium, barium, and lead levels from the RCRA unit and those levels found elsewhere on the site. Thus, a site background level needed to be determined.

ASF collected a total of 12 background samples at locations shown on Figure 3-1A of the site Closure Plan. The 12 soil sampling points were selected to represent areas not affected by any concentrated waste management or product handling activities. Background soils collected were of the same type of soil horizon as the on-site comparison samples. Sample depths were from 12 to 18 inches below grade. The sampling locations were approved by the Ohio Environmental Protection Agency (OEPA) as per the revised Closure Plan for the Electric Arc Furnace Baghouse Hazardous Waste Management Unit (RMT, 1994).

As stated in the OEPA Closure Guidance (OEPA, 1991), the UCL for each background constituent of concern (barium, cadmium, chromium, and lead) was calculated as the mean of the background population plus two times the standard deviation. The UCL was used as the point of comparison for soil samples collected in the closure area.

The general approach for statistical analysis for the establishment of the UCL was described in detail in Section 3 of the site Closure Plan. The approach involved: 1) construction of probability plots to look for regularity, outliers and to observe the general fit of the distribution; 2) the construction of box-plots to show comparison of the on-site and off-site means, standard deviation and outliers; 3) conduct Kolmogorov-Smirnov tests to determine the fit of the distribution to a normal and log-normal distribution; 4) where required, test for outliers using criteria described in Subsection 3.11.1 of the 1993 Closure Plan Guidance; and 5) where required, adjust the means and standard deviation for censored data (data below the method detection limit) using Cohens Method.

The results of the background sampling were submitted in a report, Background Sampling Analysis for Electric Arc Furnace Baghouse Hazardous Waste Management Unit (RMT, revised: June 1994), and were included in Appendix D of the approved site Closure Plan. In summary, the following background UCLs were established:

Barium	290 mg/kg
Chromium	22 mg/kg
Cadmium	1.0 mg/kg
Lead	580 mg/kg

3.4 Confirmatory Soil Sampling and Analysis Plan

To determine whether clean closure was achieved, soil samples from the RCRA unit were collected for comparison to UCLs. This was done after the excavation of contaminated materials has been completed, but prior to backfilling the excavation. OEPA guidance (1991) provides equations used to determine grid intervals and the number of samples in a given area. Using Equation 2 (for small sites less than 3 acres) for the RCRA unit, resulted in a grid interval of 64 square feet (8 feet). The guidance states that grid intervals of 25 to 100 feet are common for separation of samples for a relatively large unit. The confirmatory soil sampling plan for ASF consisted of an 8 foot grid, supplemented with additional samples, directed at specific locations to provide increased coverage and to reduce the effective grid interval. A total of 86 samples were collected from soil beneath the RCRA unit and on the sides of the unit. Samples taken on the sides were centered and toward the bottom of the grid section. Final sample locations are detailed in Section 5 of this report. Samples were classified as to soil type to verify that they were soils from the same strata as the background samples.

To determine if clean closure was achieved, samples of the underlying soil were analyzed for total cadmium, chromium, barium, and lead, using USEPA Method 6010. The results were compared to the closure limits as established in Appendix D of the Closure Plan. Initially, the soil sample from the uppermost sample interval (0 to 1 foot) was analyzed. When laboratory results indicated that cadmium, chromium, barium, or lead were present at concentrations above the closure limits in the upper sample, additional deeper samples were analyzed.

Section 4
DOCUMENTATION OF CLOSURE ACTIVITIES

4.1 Preconstruction Activities

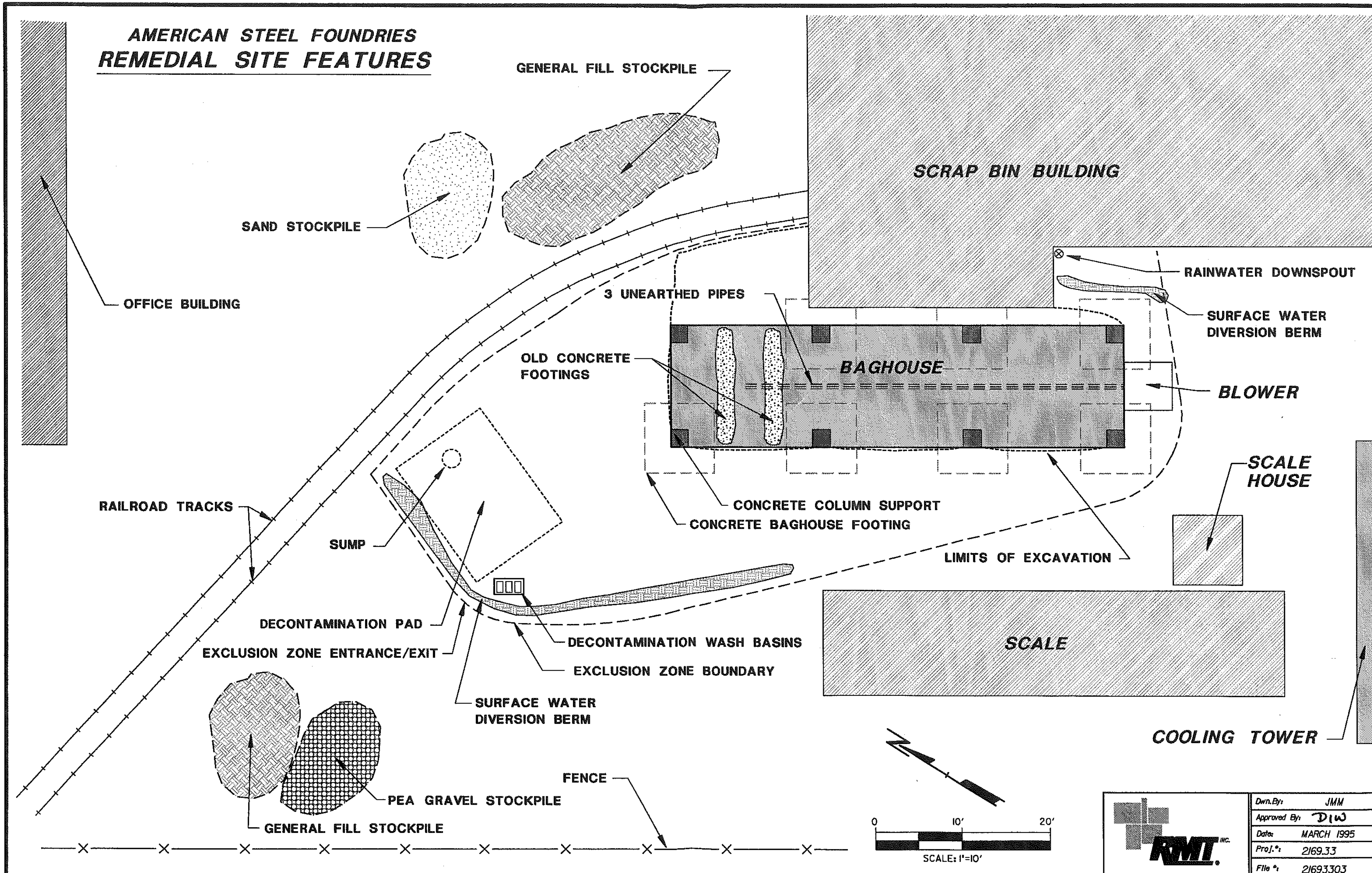
Prior to starting the closure activities, a site-specific Health and Safety Plan was developed by each company involved with closure activities to cover their on-site workers in compliance with applicable federal, state, and local requirements. These plans were reviewed by ASF and were discussed with site workers prior to closure activities.

It was agreed during preconstruction discussions, that excavation would start in the southern portion of the baghouse area and proceed north to the railroad tracks, using initial depths of excavation based on the approved Closure Plan. The limits of excavation were explained and sketched on a site plan (refer to Figure 4-1 for locations of all remedial site features). Stockpile locations for clean backfill were agreed upon by ASF and Burlington (the remediation contractor). The location of the fence to designate the boundary for the exclusion zone was established, and a location for backfill materials was selected as shown in Figure 4-1.

Before excavation of baghouse soils commenced, the decontamination pad was constructed at a location just north of the baghouse. Surface soils were excavated to grades needed for proper drainage and a hole was excavated for the sump. A layer of sand was placed in the base of the excavation and graded. Two layers of 30 milliliters (ml) geomembrane were placed over the sand and the edges were bermed to contain all runoff. The two pieces of equipment (backhoe for excavation and bobcat for loading) used for the construction were to remain within the exclusion zone at all times and be decontaminated only once, at the conclusion of construction. Therefore, it was agreed that pea gravel would be added to the pad prior to this use. Decontamination procedures for equipment and personnel were reviewed by RMT and Burlington and it was agreed that personnel and small equipment decontamination activities would be held adjacent to the decontamination pad.

4.2 Excavation of Contaminated Materials

Excavation beneath the baghouse began on August 1, 1994. Crushed limestone in the southern third of the area was excavated initially. The upper one to two feet was primarily crushed limestone and dark gray sandy soil, which was placed into a total of 58 55-gallon drums and sealed. During excavation activities the drums were stored in the scrap bin building adjacent to the baghouse. All drums were labeled and cleaned before being removed from the exclusion zone. The limestone material was retained by ASF for later reuse for charging in the EAF.



AMERICAN STEEL FOUNDRIES
REMEDIAL SITE FEATURES
GENERAL FILL STOCKPILE
SCRAP BIN BUILDING
SAND STOCKPILE
OFFICE BUILDING
RAINWATER DOWNSPOUT
3 UNEARTHED PIPES
SURFACE WATER
DIVERSION BERM
OLD CONCRETE
FOOTINGS
BAGHOUSE
BLOWER
SCALE
HOUSE
RAILROAD TRACKS
CONCRETE COLUMN SUPPORT
CONCRETE BAGHOUSE FOOTING
SUMP
LIMITS OF EXCAVATION
DECONTAMINATION PAD
DECONTAMINATION WASH BASINS
EXCLUSION ZONE ENTRANCE/EXIT
EXCLUSION ZONE BOUNDARY
SCALE
SURFACE WATER
DIVERSION BERM
COOLING TOWER
FENCE
PEA GRAVEL STOCKPILE
GENERAL FILL STOCKPILE
0
10'
20'
SCALE: 1"=10'
RMT INC.
Dwn.By: JMM
Approved By: DLW
Date: MARCH 1995
Proj.#: 2169.33
File #: 21693303

FIGURE 4-1

All remaining excavated soils were loaded into visqueen-lined rolloff boxes for later disposal at an approved off-site location. The soil in the southern area was excavated to a depth of three feet below existing grades and the limits of excavation on the east perimeter were extended to the concrete wall of the scrap bin building.

While excavating in the southern section, three pipes were uncovered. Two three-inch diameter pipes were adjacent to each other and a one and a half inch diameter pipe rested on top. The pipes were approximately two feet below the surface and were positioned length-wise down the center of the baghouse area and continued beneath the excavation in the north area. (See Figure 4-1) The pipes were corroded and appeared to have been in-place for some time. ASF investigated their records to attempt to determine the purpose of the pipes but was unable to do so. ASF decided to leave the pipes in-place and excavate around and under them to remove the contaminated soils. The first round of soil sampling in this area was then completed and the backhoe relocated to the second third of the baghouse area.

All excavations were completed by having the backhoe bucket over the excavation area and excavating and stockpiling to the north. All stockpiles of contaminated soils were maintained within the limits of excavation and these stockpiles were removed and loaded into the rolloffs by the bobcat. The backhoe was never located within the limits of excavation.

Soils in the second area were excavated to a depth of two feet below existing ground and confirmatory samples were then collected. The limits were once again extended to the concrete wall of the scrap bin building. The backhoe was relocated to the northern third of the area and the small area between the railroad tracks and baghouse. These soils were excavated and loaded into rolloffs.

During excavation in the northern area of the baghouse, two concrete foundations were discovered. Each foundation was approximately one and a half feet deep by two feet wide by twelve feet long (Figure 4-1). The footings were approximately one and a half feet below the existing ground surface and appeared to have been in-place for some time. ASF decided to have Burlington remove and decontaminate the concrete. Burlington brought in an additional bobcat equipped with a hydraulic air hammer and excavated the footings. The concrete was washed down by the high pressured decontamination spray hose and removed for disposal at another location on-site.

For the second round of excavation, the soils in the southern and central areas were removed to a depth approximately two inches above the top of the footings. Soils in these areas were sampled for the second round of confirmatory sampling.

Excavation of the northern area and the additional area to the east toward the railroad tracks took place on Monday, August 8. Excavation along the side of the railroad tracks was limited to a distance one foot from the railroad ties. The ground in this area sloped down (about 3 horizontal to 1 vertical) to a finished depth between three and three and one half feet deep. Finished slopes around the excavation perimeter varied between 2 to 1 and 1 to 1.

Laboratory sample results from the south area were reviewed and it was determined that additional excavation would be needed, and it was decided to excavate to about two inches above the bottom of the baghouse concrete footings. ASF determined that the integrity of the baghouse footings was at risk and decided that this was the limit of feasible excavation. The remainder of the second round of confirmatory sampling was completed after completing this excavation. A total of approximately 140 cubic yards of contaminated soils were excavated. Figure 4-2 shows the final excavation area.

4.3 Water Removal

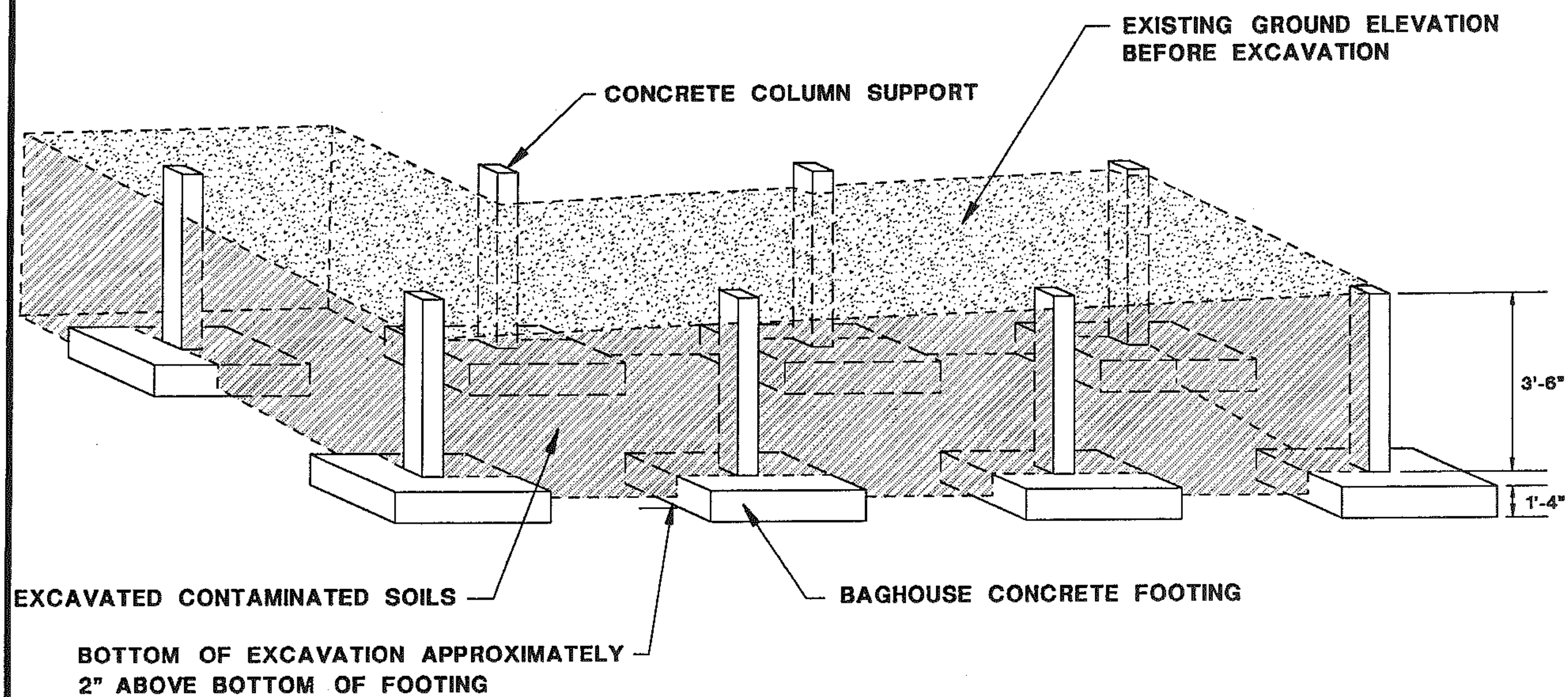
Dewatering of the excavation area was not needed during any time of construction. Rain water runoff was diverted by the use of surface water diversion berms (Figure 4-1). Rain water did not collect within the limits of excavation any time during construction.

4.4 Disposal of Contaminated Materials

Crushed limestone placed in the 55-gallon drums (58 in total) were taken to the EAF for recycling. All additional excavated soils, sampling equipment, and the decontamination pad were placed in plastic lined portable rolloffs and properly disposed at Envirite in Canton, Ohio. Latex rubber gloves and boots were properly disposed at Envirite in Canton, Ohio or, subsequent to receipt of nonhazardous analytical results, at a BFI facility in Lowellville, Ohio. Copies of manifests were included in Appendix C of the September 1994 Construction Observation Documentation Report.

The only contaminated water on-site was collected from the sump in the decontamination pad. This water was pumped and placed into plastic 55-gallon drums. The drums were temporarily stored adjacent to the decontamination pad. Upon completion of construction activities ASF planned to dispose of the water through the Alliance POTW. The approval letter from the Alliance POTW was included in Appendix C of the September 1994 Documentation Report.

AMERICAN STEEL FOUNDRIES
BAGHOUSE EXCAVATION SOILS



RMT INC.	
Dwn. By:	JMM
Approved By:	DIW
Date:	MARCH 1995
Proj. #:	2169.33
File #:	21693305

FIGURE 4-2

4.5 Backfilling of Excavation

Backfilling of the excavation area was completed in all three sections, beginning with the southern area. Initially, a single layer of 10 ml visqueen was placed in the bottom of the excavation and a one-foot layer of clean fill material (brown silty soil) was placed and compacted with a hand operated vibratory compactor. Two overlapping compaction passes were completed on this first lift and another six inch lift was placed and compacted using the same methods. A six-inch layer of sand was placed on the one and a half foot thick general fill layer, and was compacted by the same methods used on the general fill.

An independent contractor placed a concrete layer over the top of the backfill material on August 10th, following completion of excavation backfill. Cleanup of the site was completed Wednesday, August 10th.

Photographic documentation for excavation and closure activities were included in Appendix B of the August 1994 Construction Observation Documentation Report.

Section 5

CONFIRMATORY SOIL SAMPLING AND ANALYSIS

5.1 Sampling Procedures

Following the first round of excavation, and the final excavation, soil samples were collected by Burlington Environmental at locations designated by RMT. All samples were placed in clean sample jars and properly labeled. Samples were then immediately placed in coolers on ice and shipped to the RMT Laboratory, in Madison, Wisconsin using proper Chain of Custody procedures.

5.2 Sample Locations

The first round of sampling consisted of sample collection from the base or sides of the initial excavation at depths of two feet (southern third) or three feet (central and northern areas) as planned in the approved Closure Plan. Samples TS-1 through TS-21 at the base of the excavation (Figure 5-1) were obtained by digging approximately two inches below the surface with a precleaned stainless steel spoon and placing the samples directly in the sample jars. After this set of samples (21 total) was collected, another set of samples designated BS-1 through BS-21, was obtained one foot deeper in the same locations using a clean, decontaminated stainless steel spoon, after digging to this depth with a shovel.

The second round of confirmatory samples was obtained after completing the excavation to a depth approximately two inches above the bottom of the concrete footings. Samples ITS-1 through ITS-21 (Figure 5-2) were collected approximately two inches below the surface of the excavation with a decontaminated stainless steel spoon. A second sample set, IBS-1 through IBS-21, was collected by digging one foot deeper, and removing an additional two inches with the spoon. A single sample, C-1, was taken two feet below the bottom surface of the excavation.

A total of 85 samples was collected and sent to the laboratory for analysis.

5.3 Analysis and Comparison to Upper Confidence Limits

All soil samples were analyzed in the laboratory for total barium, cadmium, chromium and lead, using SW-846 Method 6010. Laboratory reports were included in Appendix A of the September 1994 Documentation Report. The results were compared to the upper confidence limits (UCL) which were statistically calculated from the analyses of twelve background samples (see Appendix D of Closure Plan, Background Sampling Analysis for Electric Arc Furnace Baghouse Hazardous Waste Management Unit, RMT, Revised, June 1994). The UCLs, as calculated, are:

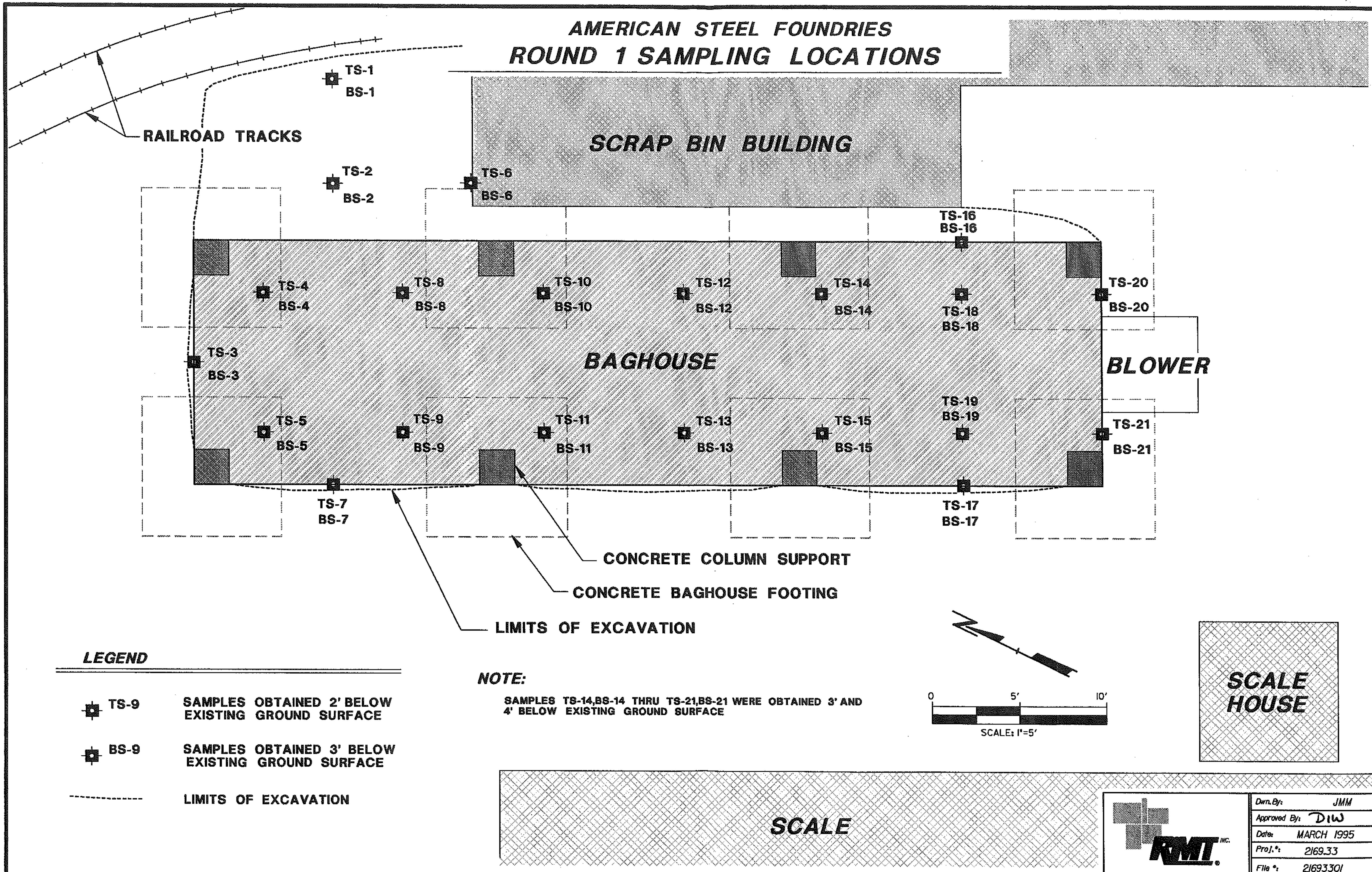

AMERICAN STEEL FOUNDRIES
ROUND 1 SAMPLING LOCATIONS
RAILROAD TRACKS
SCRAP BIN BUILDING
BAGHOUSE
BLOWER
TS-1
BS-1
TS-2
BS-2
TS-3
BS-3
TS-4
BS-4
TS-5
BS-5
TS-6
BS-6
TS-7
BS-7
TS-8
BS-8
TS-9
BS-9
TS-10
BS-10
TS-11
BS-11
TS-12
BS-12
TS-13
BS-13
TS-14
BS-14
TS-15
BS-15
TS-16
BS-16
TS-17
BS-17
TS-18
BS-18
TS-19
BS-19
TS-20
BS-20
TS-21
BS-21
CONCRETE COLUMN SUPPORT
CONCRETE BAGHOUSE FOOTING
LIMITS OF EXCAVATION
LEGEND
TS-9 SAMPLES OBTAINED 2' BELOW EXISTING GROUND SURFACE
BS-9 SAMPLES OBTAINED 3' BELOW EXISTING GROUND SURFACE
LIMITS OF EXCAVATION
NOTE:
SAMPLES TS-14,BS-14 THRU TS-21,BS-21 WERE OBTAINED 3' AND 4' BELOW EXISTING GROUND SURFACE
0
5'
10'
SCALE: 1"=5'
SCALE HOUSE
SCALE
RMT INC.
Dwn. By: JMM
Approved By: DIW
Date: MARCH 1995
Proj.#: 2169.33
File #: 21693301

FIGURE 5-1

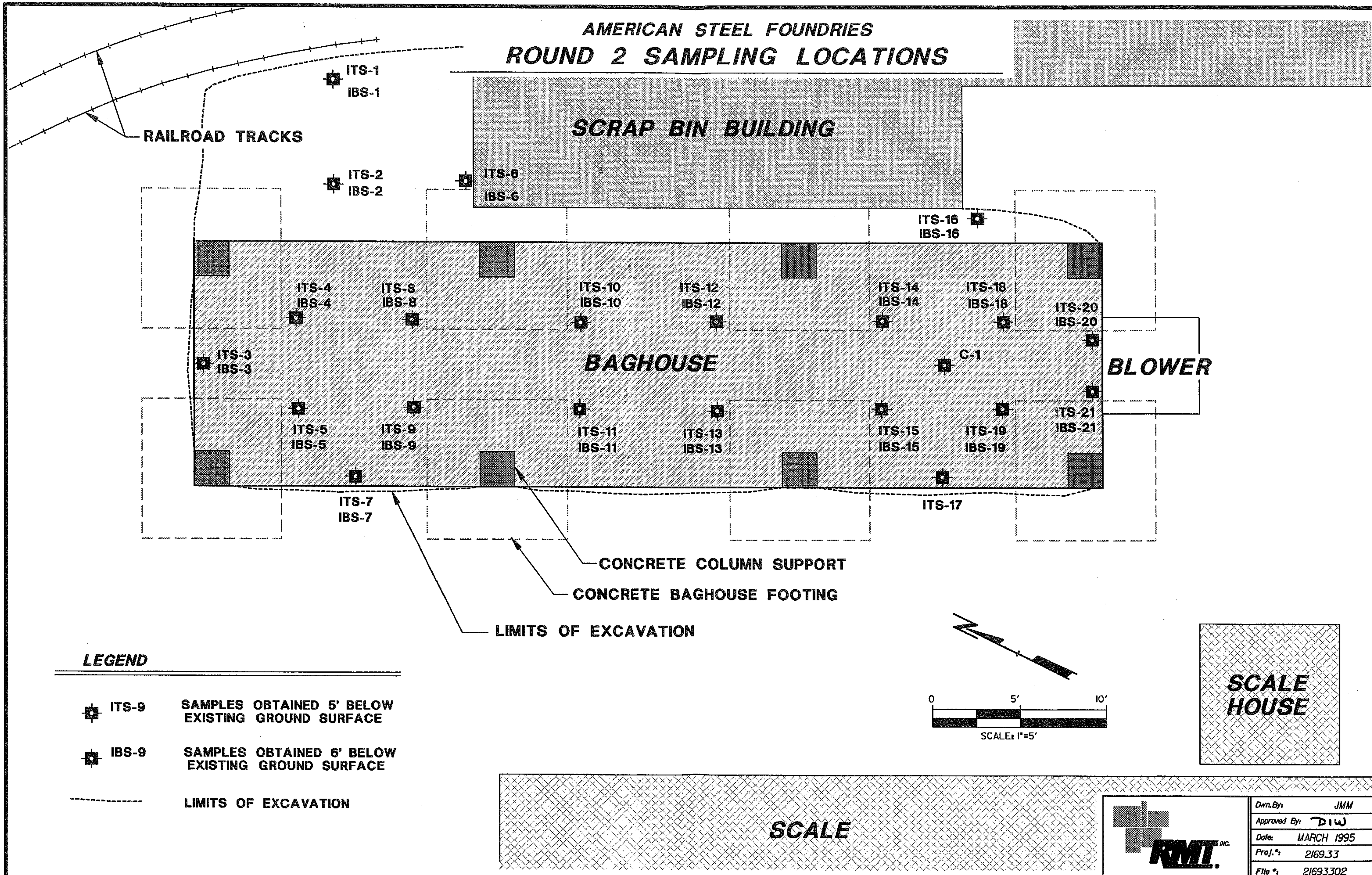

AMERICAN STEEL FOUNDRIES
ROUND 2 SAMPLING LOCATIONS
SCRAP BIN BUILDING
RAILROAD TRACKS
ITS-1
IBS-1
ITS-2
IBS-2
ITS-6
IBS-6
ITS-16
IBS-16
ITS-3
IBS-3
ITS-4
IBS-4
ITS-8
IBS-8
ITS-10
IBS-10
ITS-12
IBS-12
ITS-14
IBS-14
ITS-18
IBS-18
ITS-20
IBS-20
BAGHOUSE
C-1
BLOWER
ITS-5
IBS-5
ITS-9
IBS-9
ITS-11
IBS-11
ITS-13
IBS-13
ITS-15
IBS-15
ITS-19
IBS-19
ITS-21
IBS-21
ITS-7
IBS-7
ITS-17
CONCRETE COLUMN SUPPORT
CONCRETE BAGHOUSE FOOTING
LIMITS OF EXCAVATION
LEGEND
ITS-9 SAMPLES OBTAINED 5' BELOW EXISTING GROUND SURFACE
IBS-9 SAMPLES OBTAINED 6' BELOW EXISTING GROUND SURFACE
LIMITS OF EXCAVATION
0
5'
10'
SCALE: 1"=5'
SCALE HOUSE
SCALE
RMT INC.
Dwn.By: JMM
Approved By: DIW
Date: MARCH 1995
Proj.#: 2169.33
File #: 21693302

FIGURE 5-2

Barium	290 mg/kg
Cadmium	1.0 mg/kg
Chromium	22 mg/kg
Lead	580 mg/kg

Tables 5-1 and 5-2 show the results from the first and second rounds of confirmatory sampling, and a comparison to the UCLs. Any analysis which is above the UCL is shaded.

5.3.1 First Round of Confirmatory Sampling

The first round of confirmatory sampling showed that the following locations had levels of barium, cadmium, chromium and lead below the respective UCLs at the deeper sample depth: BS-3, BS-4, BS-9, BS-10, and BS-14. S-17 was the only first round location where both depths had all results below the UCLs. The UCL for barium was slightly exceeded only at TS-11 and BS-13.

5.3.2 Second Round of Confirmatory Sampling

The second round of confirmatory sampling, taken after the final excavation, showed that the following locations had levels for all four metals below the UCLs at both sampling depths: S-4 and S-14. The deeper samples which had all metals below the UCLs were IBS-1, IBS-4, IBS-7, IBS-12, IBS-14, IBS-20 and IBS-21. Only two sampling locations, (IBS-6 and IBS-21 had levels of barium (390 mg/kg and 350 mg/kg, respectively) above the UCL.

Eleven of the sample locations (S-1, S-2, S-3, S-5, S-6, S-7, S-8, S-10, S-15, S-18 and S-19) had levels of cadmium exceeding the UCL of 1.0 mg/kg. These levels ranged from 1.1 mg/kg to 33 mg/kg. Fifteen sample locations, (S-1, S-2, S-5, S-6, S-8, S-9, S-10, S-11, S-12, S-13, S-15, S-16, S-17, S-18 and S-20) had levels of chromium above the chromium UCL of 22 mg/kg. These levels ranged from 25 mg/kg to 120 mg/kg.

Only one sample, ITS-15, had a lead level above the UCL of 580 mg/kg. The first sample showed 1700 mg/kg lead. Because this level was significantly higher than any lead levels from other locations, the laboratory was asked to take a second sample from the sampling container and analyze for all four metals. The second set of results for ITS-15 are shown in parentheses on Table 5-2. The second analysis showed the

Table 5-1
FIRST ROUND CONFIRMATORY SAMPLE ANALYSES
American Steel Foundries, Alliance, Ohio
August 1994

Sample Location	ANALYTICAL RESULT (mg/kg dry weight)			
	Barium	Cadmium	Chromium	Lead
UCL	290	1.0	22	580
TS-1	33	1.3	27	65
BS-1	64	1.9	33	120
TS-2	110	44	350	1300
BS-2	190	7.2	34	160
TS-3	40	1.2	34	63
BS-3	28	1.0	16*	32
TS-4	140	8.9	67	470
BS-4	120	<0.62	20	52
TS-5	79	<0.67	96	130
BS-5	77	<0.61	41	120
TS-6	140	3.5	50	140
BS-6	34	<0.68	32	94
TS-7	77	36	270	1200
BS-7	52	3.6	26	32
TS-8	49	<0.60	27	110
BS-8	48	<0.65	23	110
TS-9	100 I	<0.65	34	66
BS-9	270	<0.69	11	<14
TS-10	30	0.96	62	40
BS-10	44	<0.74	18	33
TS-11	300	1.8	28	36
BS-11	240	3.0	28	110
TS-12	54	1.1	60 P*	61
BS-12	16	<0.68	97	33

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Table 5-1, cont.
FIRST ROUND CONFIRMATORY SAMPLE ANALYSES
American Steel Foundries, Alliance, Ohio
August 1994

Sample Location	ANALYTICAL RESULT (mg/kg dry weight)			
	Barium	Cadmium	Chromium	Lead
UCL	**290**	**1.0**	**22**	**580**
TS-13	190	2.4	61	160
TS-13	320	<0.69	7.0	<14
TS-14	70	12	94 P	850
BS-14	24	<0.59	17	69
TS-15	130	2.5	240	150
BS-15	190	1.3	17	60
TS-16	42	6.8	79 P*	2300 P*
BS-16	150	18	93	920
TS-17	7.4	<0.64	16	20
BS-17	20	0.79	9.4	29
TS-18	46	7.4	73	1100
BS-18	25	1.3	28	370
TS-19	74	24	190	1100
BS-19	220	1.4	14	53
TS-20	43	6.3	65	890
BS-20	28	3.4	45	470
TS-21	160	55	310	2700
BS-21	110	3.6	48	230

Notes: * Duplicate analyses not within control limits.
P Digested spike recovery failed accuracy criteria; post-digestion spike recovery accepted.
I Estimated concentration due to severe matrix interferences.
Values exceeding the UCL are shaded.

Table 5-2
SECOND ROUND CONFIRMATORY SAMPLE ANALYSES
American Steel Foundries, Alliance, Ohio
August 1994

Sample Location	ANALYTICAL RESULT (mg/kg dry weight)			
	Barium	Cadmium	Chromium	Lead
UCL	290	1.0	22	580
ITS-1	190	3.5	92	160
IBS-1	120	<0.86	20	34
ITS-2	240 P	4.9	34 P*	120
IBS-2	49	<0.69	120	48
ITS-3	15	<0.74	3.0	<15
IBS-3	20	1.5	6.4	<14
ITS-4	21	<0.63	8.0	<13
IBS-4	49	0.78	16	20
ITS-5	35	2.4	49	110
IBS-5	39	3.0	32	29
ITS-6	220	2.7	69	170
IBS-6	390	1.5	18	35
ITS-7	17	1.2	5.3	17
IBS-7	14	0.95	9.1	24
ITS-8	54	2.6	40	160
IBS-8	57	1.2	64	160
ITS-9	82	0.96	59	110
IBS-9	210	<0.69	29	72
ITS-10	26	1.8	8.4	59
IBS-10	110	5.4	43	230
ITS-11	160	<0.61	41	59
IBS-11	110	0.80	77	82
ITS-12	28	<0.69	24 P*	24
IBS-12	63	0.85	13	200

Table 5-2, cont.
SECOND ROUND CONFIRMATORY SAMPLE ANALYSES
American Steel Foundries, Alliance, Ohio
August 1994

Sample Location	ANALYTICAL RESULT (mg/kg dry weight)			
	Barium	Cadmium	Chromium	Lead
UCL	**290**	**1.0**	**22**	**580**
ITS-13	290	0.77	8.8	<15
IBS-13	77	<0.72	69	60
ITS-14	46	0.87	16	81
IBS-14	21	<0.62	22	49
ITS-15	110 (130)	33 (21)	210 (140)	1700 (1100)
IBS-15	70	<0.64	33	61
ITS-16	130	<0.65	34	23
IBS-16	220	0.69	25	22
ITS-17	10	<0.71	11	<14
IBS-17	25	<0.89	83	95
ITS-18	42	6.5	28 P	82*
IBS-18	49	10	38	120
ITS-19	180	1.1	16	36
IBS-19	290	1.1	17	100
ITS-20	260	0.66	29	29
IBS-20	84	0.93	16	<16
ITS-21	350	0.80	9.4	25
IBS-21	290	<0.82	7.8	<16
C-1	78	1.7	17	<13

Notes: * Duplicate analyses not within control limits.
P Digested spike recovery failed accuracy criteria; post-digestion spike recovery accepted.
Values exceeding the UCL are shaded.

lead level to be 1100 mg/kg. The sample taken at the deeper depth, at location IBS-15, had a lead level of 61 mg/kg, which is well below the UCL of 583 mg/kg.

One sample, C-1, was collected at a depth of two feet below the base of the excavation near the center of the southern area. This sample showed only cadmium exceeding the UCL at a concentration of 1.7 mg/kg. It should also be noted that the second round samples had both a much lower frequency of UCL exceedances than the first round, and these exceedances were at significantly lower concentrations. Cadmium concentrations in the first round ranged from <0.59 to 55 mg/kg, and chromium ranged from 11 to 350 mg/kg. For the second round samples (with the exception of ITS-15 which is discussed above), cadmium concentrations were <0.61 to a high of 6.5 mg/kg, and chromium ranged from 3.0 to 120 mg/kg.

Section 6
DECONTAMINATION

6.1 Site Control

Access to the closure construction area was maintained by a four-foot high temporary perimeter fence. Entrance/exit access was limited to a small portion of the fence that was located adjacent to the decontamination pad. Only Burlington Environmental, RMT, and authorized ASF personnel were permitted to enter and exit the exclusion zone. A small portion of the fence was lowered at the beginning of the day and then returned to its position during breaks and at the end of each day (refer to Figure 3-1 for fence boundary location).

6.2 Personnel Decontamination

Personnel exiting the exclusion zone area were decontaminated by one of two methods. The first method involved a series of three basins filled with clean water. Each basin contained its own scrub brush and the personnel leaving the area would wash both boots and gloves through each basin until all visible residue was removed. The second method of decontamination was immediate removal and disposal of latex boots and gloves. At the end of the work day these boots and gloves were placed within one of the rolloffs containing contaminated waste material and treated as such. All used boots and gloves were disposed within the waste containers at the completion of construction.

6.3 Equipment Decontamination

Decontamination of construction vehicles was kept to a minimum to generate least amount of liquid waste. The ability to remain within the exclusion zone during the construction period enabled the bobcat and backhoe to be washed off with high pressure equipment a total of six and three times, respectively. The backhoe was able to remain within the exclusion zone during construction and exited only to reposition itself for additional excavations and to dig a test pit in a different location. The bobcat exited the zone to relocate the rolloffs during loading procedures. Whenever exiting the exclusion zone the bobcat was decontaminated.

6.4 Closure of Decontamination Pad

At the completion of construction activities the entire decontamination pad and associated materials were disposed within the last rolloff. ASF disposed of the pad as hazardous materials in the same manner as the excavated soil.

A.4.4

BACKGROUND SAMPLING ANALYSIS
FOR
ELECTRIC ARC FURNACE BAGHOUSE
HAZARDOUS WASTE MANAGEMENT UNIT

PREPARED FOR
AMERICAN STEEL FOUNDRIES
ALLIANCE, OHIO

PREPARED BY
RMT, INC.
SCHAUMBURG, ILLINOIS

NOVEMBER 1993

REVISED: JUNE 1994

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Section 1
BACKGROUND

Soil samples were collected and analyzed to determine background concentrations for barium, cadmium, chromium, and lead. Six samples were collected off-site and six samples were collected on-site (Figure 1). The sampling locations were approved by the Ohio Environmental Protection Agency (OEPA) as per the revised Closure Plan for the Electric Arc Furnace Baghouse Hazardous Waste Management Unit (RMT, 1993). In accordance with the closure plan, the Upper Confidence Limit (UCL) for each consistent of concern will be calculated as the mean of the background population plus two times the standard deviation. The UCL will be used as the point of comparison for soil samples collected in the closure area.

Section 2
SUMMARY

The general approach for statistical analysis for the establishment of the UCL is described in detail in Section 3. The approach involved: 1) construction of probability plots to look for regularity, outliers and to observe the general fit of the distribution; 2) the construction of box-plots to show comparison of the on-site and off-site means, standard deviation and outliers; 3) conduct Kolmogorov-Smirnov tests to determine the fit of the distribution to a normal and log-normal distribution; 4) where required, test for outliers using criteria described in Subsection 3.11.1 of the 1993 Closure Plan Guidance; and 5) where required, adjust the means and standard deviation for censored data (data below the method detection limit) using Cohens Method.

Based on the statistical analysis, the UCLs for background samples were established and are shown in Table 1.

Section 3

STATISTICAL ANALYSIS

3.1 General

Table 2 summarizes the analytical results used for setting the UCLs for the off-site and on-site analytes. Copies of the analytical reports are located in Appendix A. Sample Numbers 006 and 007 are laboratory duplicates; hence for the statistical analysis we have used the average of the two reported values for each analyte. The laboratory samples 006 and 007 are two separate samples taken from the same advancement of the hand auger. Field duplicates are taken to determine homogeneity of solid matrices; not to demonstrate precision or accuracy of sampling results. The difference between analytical results for the two samples reflects the non-homogeneity of the foundry matrix.

The general approach for statistical analysis of the data is as follows:

- Plot probability distributions and look for regularity, outliers and general fit of the distribution.
- Plot box-plots to show comparison of means, standard deviations and outliers.
- Conduct the one sample Kolmogorov-Smirnov test with Lilliefors Critical Values to determine fit of distribution and conduct two sample Kolmogorov-Smirnov test to determine whether the off-site and on-site samples could have come from the same distribution.
- Where required, test for outliers using the method outliers in Subsection 3.11.1 of the 1993 Closure Plan Guidance
- Where required, adjust means and standard deviations for censored data (data below the method detection limit) using Cohens Method.

3.2 Barium

3.2.1 Assessment of the Underlying Distribution

Figure 2 shows on-site, off-site and combined (all data) probability plots of the barium concentration observed in the soil samples.

Kolmogorov-Smirnov statistics were calculated for the plots to determine lack of fit of the data to a normal and log normal distribution as follows:

Assumed Distribution	K-S Statistic	Lilliefors Critical Value for N=6 and α=0.5
On-site Normal	0.1732	0.319
On-site Log Normal	0.3367	0.319
Off-site Normal	0.1832	0.319
Off-site Log Normal	0.1822	0.319

The KS statistics for the log-normal transformation of on-site barium concentration exceeded the Lilliefors critical value. Hence, the hypothesis that the data fit a log normal distribution was rejected.

The KS statistic for the on-site barium concentration normal distribution was 0.1732 which is less than the Lilliefors critical value, hence the hypothesis that the on-site barium fits a normal distribution could not be rejected.

The KS statistics for the off-site barium concentration for both the normal and log-normal distribution were less than the Lilliefors critical value, hence the hypothesis that both the log normal and normal distribution fit the data could not be rejected.

3.2.2 Comparison of On-Site and Off-Site Barium Concentrations

Based on the assumption that the underlying distribution of the on-site and off-site barium concentration is normal, comparisons were made of the mean and variance of the two distributions. These are summarized as follows:

	On-site	Off-Site	Pooled
Mean (mg/kg)	86.43	146.28	116.358
Difference Between Means (mg/kg)	59.85		
Variance	6034.15	8333.5	7183.82
Standard Deviation (mg/kg)	77.68	91.29	84.7574
Computed t-statistic = -1.223	-1.233		
Critical t (α = 0.5, ν = 10)	2.015		

To compare the means, a Student t-test was applied to the difference between the means. The calculated t value was -1.223; the critical t value for α = .05 and 10 degrees of freedom is 2.015; thus the null hypothesis of equal means is accepted.

3.2.3 Comparison of the On-Site and Off-Site Barium Variances

Based on the observed variance ratio of:

$$\frac{6034.15}{8333.5} = 0.724$$

and the corresponding 95 percent confidence interval of 0.1032 to 5.1745, the variances are assumed to be equal.

3.2.4 Adjustment of the Mean and Standard Deviation for Values Below the Detection Limit

One of the barium values was below the method detection limit. The mean and standard deviations were adjusted by Cohen's Method (1961) as follows:

$$n = 12 \quad k = 11$$

$$\therefore h = \frac{12 - 11}{12} = 0.0833$$

$$\overline{Yu} = \frac{l}{k} \Sigma\ Yl = 126.89$$

$$S^2u = \frac{l}{k} \Sigma\ (Yi - \overline{Yu})^2 = 6195.33$$

$$\alpha = \frac{S^2u}{(Yu - \overline{Yo})^2} = \frac{6195.33}{(125.89)} = .3909$$

$$\therefore \lambda\ (h = 0.0833,\ \alpha = .3909) = 0.0954$$

$$\therefore \mu y = \overline{Yu} - \lambda\ (\overline{Yu} - Yo)^2 = 126.89 - .0954\ (125.89) = 114.88$$

$$\sigma^2\ y = S^2u + \lambda\ (\overline{Yu} - Yo)^2 = 6195 + .0954\ (125.89)^2 = 7706.9$$

$$\sigma y = \sqrt[2]{7706.9} = 87.78$$

It should be noted that the estimated mean and standard deviation by Cohens Method are only slightly different from those based on using one-half the detection limit for the value below the detection limit.

3.2.5 Estimation of the UCL for Barium

The UCL for barium estimated from the pooled data is as follows:

μg = mean concentration = 114.88
σy = standard deviation = 87.78
UCL = 114.88+2(87.78)=290.44 mg/kg

3.3 Cadmium

All values for cadmium were below the method detection limit (MDL). Hence, the UCL for cadmium is the MDL of 1 mg/kg.

3.4 Chromium

3.4.1 Assessment of the Underlying Distribution

Figure 3 shows probability plots of the on-site, off-site and combined data for chromium.

Visual inspection of the probability plots suggests that a log transformation of the data is appropriate. In order to test this hypothesis, Kolmogorov-Smirnov statistics were calculated. The on-site and off-site chromium and compared with the Lilliefors critical value for N=6 and α=0.05 as follows:

	KS Statistic	Lilliefors Critical Value
Normal on-site	0.4250*	0.319
Normal off-site	0.1677	0.319
Log normal on-site	0.3078	0.319
Log normal off-site	0.1477	0.319

Thus, the assumptions for the normal distribution of the on-site chromium concentration do not meet the criteria of fit for the Lilliefors critical value.

The lack of fit of the on-site chromium normal distribution is likely caused by the uniquely large value of 2330 mg/kg. To test whether this value can be considered an outlier, the criteria in Section 3.11.1 of the 1993 Closure Plan Review Guidance was employed as follows:

Upper cut off = Upper quartile + 1.5 (interquartile range)

= 260 + 1.5 (190.1)

= 260 + 285.15

= 545.15 mg/kg

Thus, the single value of 2,330 mg/kg is above the cutoff. Therefore, this value was eliminated from the data set for determining the UCL for chromium.

Recalculation of the Kolmogorov-Smirnov statistic for the on-site values yielded the following values.

	KS Statistic	Lilliefors Critical Value
Normal on-site	0.352	0.381
Log normal on-site	0.393	0.381

Thus, the data appear to fit the normal distribution if the single outlier is discarded.

3.4.2 Comparison of the On-Site and Off-Site Chromium Concentration Means

Based on the assumption that the on-site and off-site chromium concentrations are normally distributed, comparisons were made of the means of the two distributions:

	On-site	Off-site
Mean (mg/Kg)	100.33	16.56
Difference Between Means (mg/kg)	83.767	
Variance	9186.04	11.4347
Standard deviation (mg/Kg)	95.84	3.38

Computed t statistic = 2.163

Critical $t(\alpha=.05, \nu=10) = 2.262$

At the 95 percent confidence level, the hypothesis that the means are equal, cannot be rejected.

3.4.3 Comparison of the On-Site and Off-Site Chromium Variances

The variance ratio was calculated to be 803.35. The critical F ratio ($\alpha=.95$, $\nu_1=4$, and $\nu_2=5$) is 7.39. Thus the hypothesis that the variances of on-site and off-site distributions are equal, must be rejected.

3.4.4 Kolmogorov-Smirnov Two-Sided Test to Compare On-Site and Off-Site Chromium Distribution

A further test was conducted to determine whether the on-site and off-site chromium values could have arisen from the same distribution.

The two-sample Kolmogorov-Smirnov test was done to compare the two distributions.

KS statistic = 0.8
Critical value = 2/3 = 0.67

Hence, we reject the hypothesis that the data are from the same distribution.

3.4.5 Estimation of the UCL for Chromium

Based on the above analyses, the off-site chromium values were used to establish the UCL as follows:

$$\begin{aligned} \text{UCL} &= \bar{y} + 2S \\ \text{UCL} &= 16.56 + 2(3.381) \\ &= 16.56 + 6.762 \\ &= 23.32 \text{ mg/kg} \end{aligned}$$

3.5 Lead

3.5.1 Assessment of the Underlying Distribution

Figure 4 shows probability plots for on-site, off-site, and all data for lead values observed in the soil samples.

Kolmogorov-Smirnov statistics were calculated for the data to determine lack-of-fit of the distribution for a normal and log-normal distribution as follows:

Assumed	KS Statistic	Lilliefors Critical Value
On-site normal	0.3985*	0.319
On-site log normal	0.2983	0.319
Off-site normal	0.3436*	0.319
Off-site log normal	0.2820	0.319

* Exceeds Lilliefors critical value.

The Lilliefors critical values were exceeded by both the on-site and off-site lead normal distribution data indicating that a log-normal transformation would best fit the data.

Based on these results, we have assumed that the underlying distribution for lead is log normal.

3.5.2 Comparison of Off-Site and On-Site Mean Lead Concentrations

Based on the assumption that both on-site and off-site lead concentrations are log-normally distributed, comparisons were made of the means of the two distributions as follows.

	On-site	Off-site
n =	6	6
Mean ($\log_{10}$ mg/kg)	1.444	2.005
Difference ($\log_{10}$ mg/kg)	-.5607	
Variance	0.2236	0.3182
Standard deviation ($\log_{10}$ mg/kg)	0.4728	0.5641
Calculated t = -1.86417		
Critical t (α=0.5, ν=10) = 2.262		

Accept H_o; that is that there is no statistical difference in the means.

3.5.3 Comparison of On-Site and Off-Site Variances for Lead

The variance ratio for on-site and off-site lead is 0.2236/0.3182 = 0.7027. The critical F (α=.95, ν_1=5, ν_2=5) = 1.89. Thus the hypothesis that the variances are equal is accepted.

3.5.4 Calculation of UCL for Lead

Based on the above results, the UCL for lead is based on the assumption of a log-normal distribution and the pooled standard deviation. Therefore:

$$\text{Log (UCL)} = \bar{y} + 2S$$

Where: $\bar{y} = \dfrac{\Sigma \log y_i}{n}$

and: $S = \sqrt{\Sigma} (\log y_i - \overline{\log y})/n\text{-}1$

$$\text{Log (UCL)} = 1.725 + 2\ (0.52047)$$
$$= 1.725 + 1.04094 = 2.76594$$

Anti-log (2.76594) = 583.36 mg/kg

Table 1
UCLs for Background Samples

Constituent	Estimated Mean (mg/kg)	Estimated Standard Deviation	UCL (mg/kg)
Barium	114.88	87.78	290.44
Chromium	16.56	3.381	22.329
Cadmium	NA	NA	1.0
Lead ($\log_{10}$)	1.725	0.520	583.36

Table 2

DATA USED FOR SETTING UCL FOR BACKGROUND CONCENTRATIONS						
Lab Sample No.	Loc. #	Description	Analyte Concentration, mg/kg			
			Barium	Cadmium	Chromium	Lead
001	11	on-site	9.3	<1.0	69.9	25.3
002	12	on-site	85.5	<1.0	2330.0	25.7
003	9	on-site	212.0	<1.0	87.6	25.9
004	10	on-site	92.8	<1.0	260.0	36.3
005	8	on-site	<1.0	<1.0	<2.0	<10.0
006	7	on-site	119.0	<1.0	69.3	63.6
007[1]	Field Dup. of 7	on-site	118.0	<1.0	97.0	241.0
008	3	off-site	148.0	<1.0	12.7	148.0
003	4	off-site	103.0	<1.0	16.7	16.8
0010	6	off-site	296.0	<1.0	19.5	498.0
0011	5	off-site	61.1	<1.0	15.1	12.0
0012	2	off-site	64.6	<1.0	13.9	43.6
0013	1	off-site	205.0	<1.0	21.5	165.0

[1] Samples 006 and 007 are lab duplicates; used average in statistical analysis

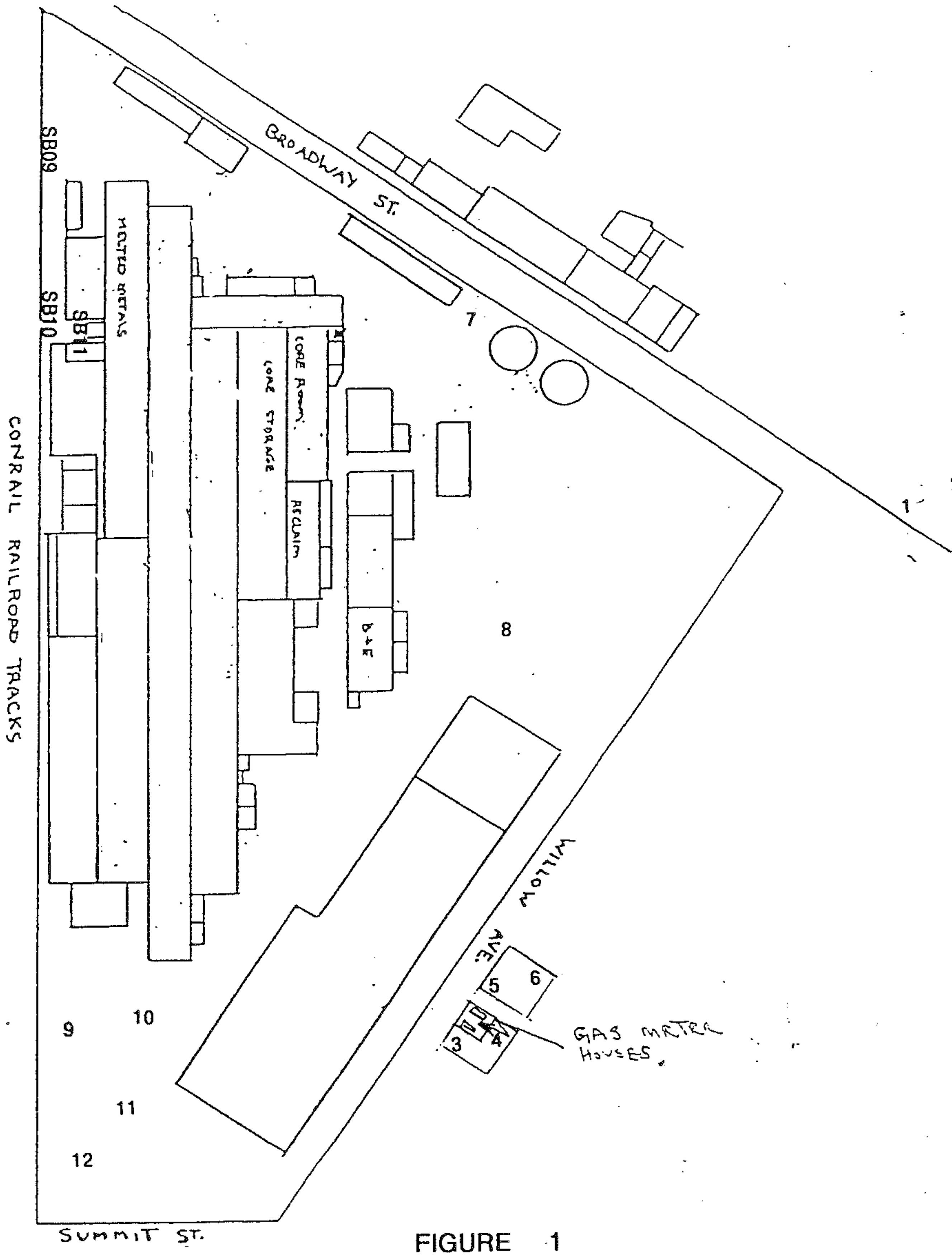
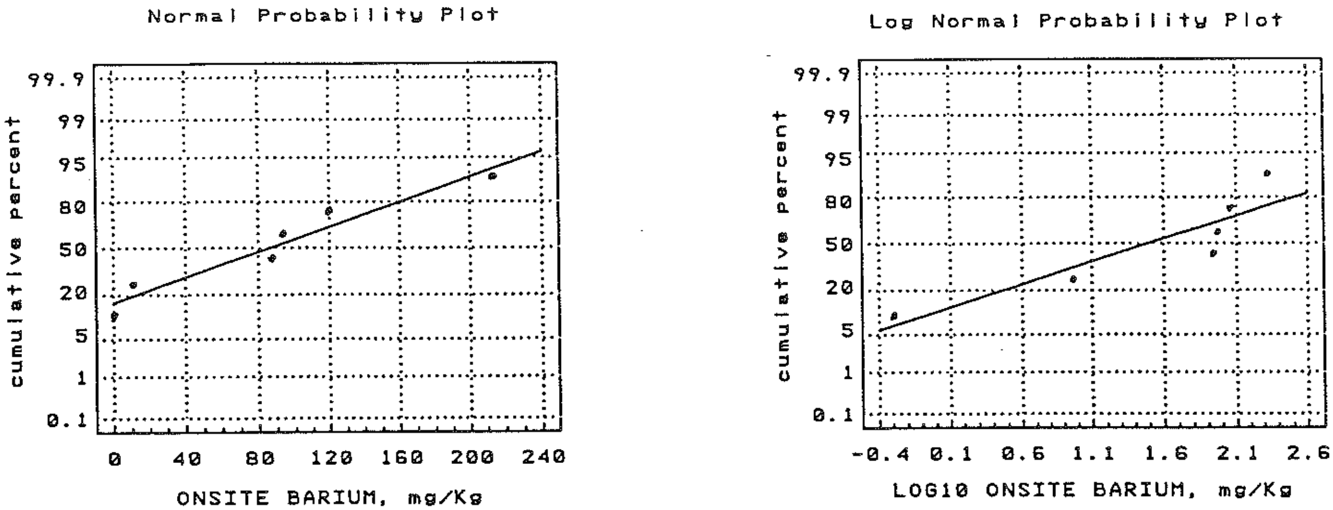
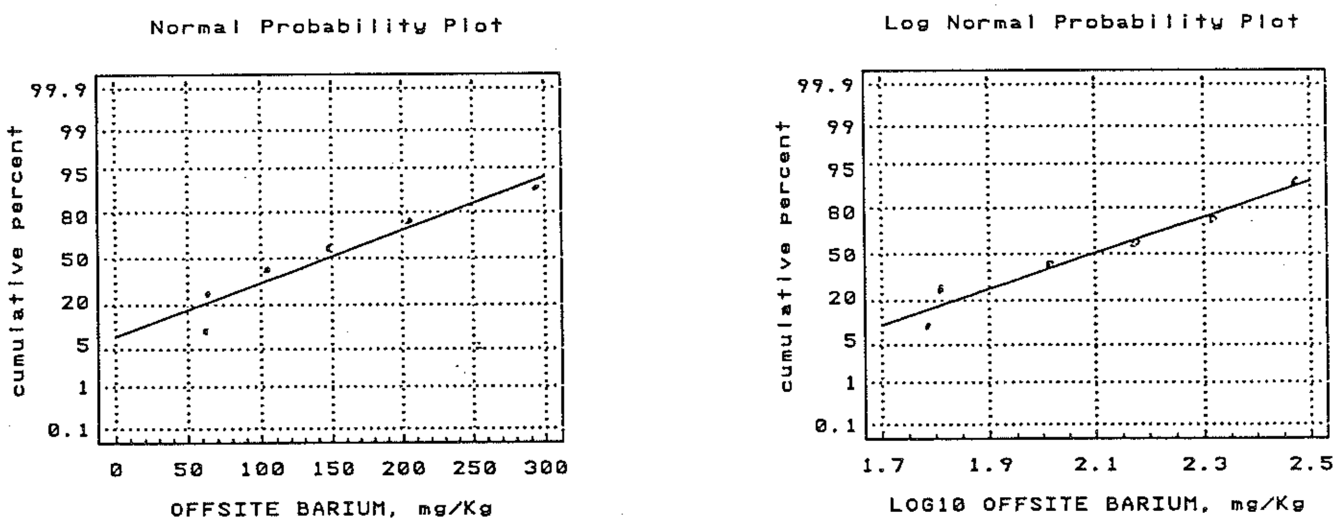


FIGURE 1

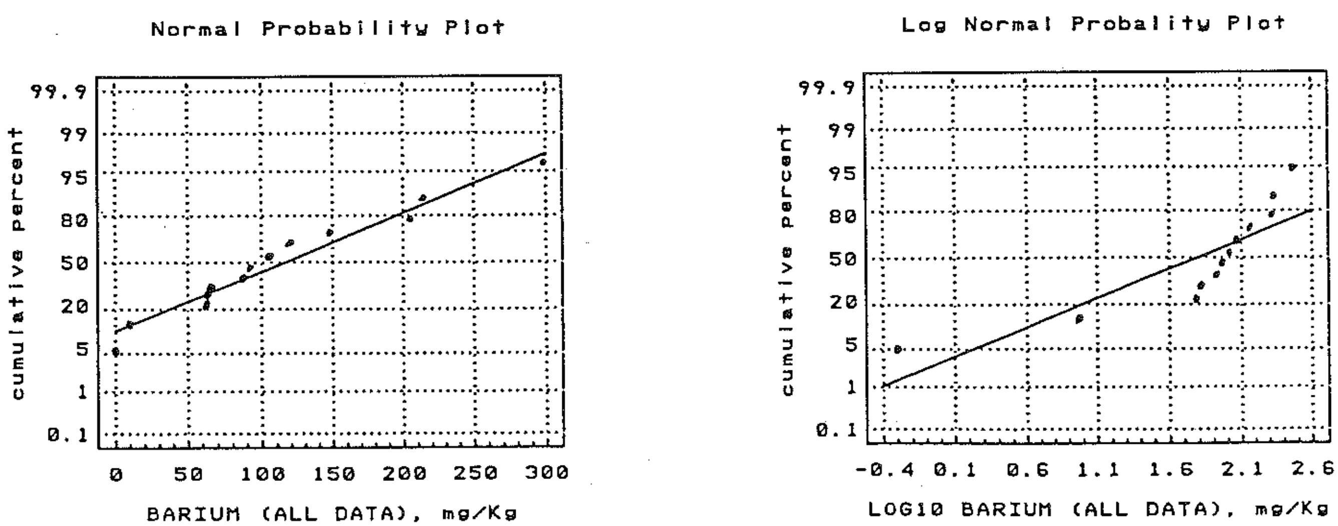
12 BACKGROUND SOILS SAMPLING LOCATIONS



a. ONSITE BARIUM

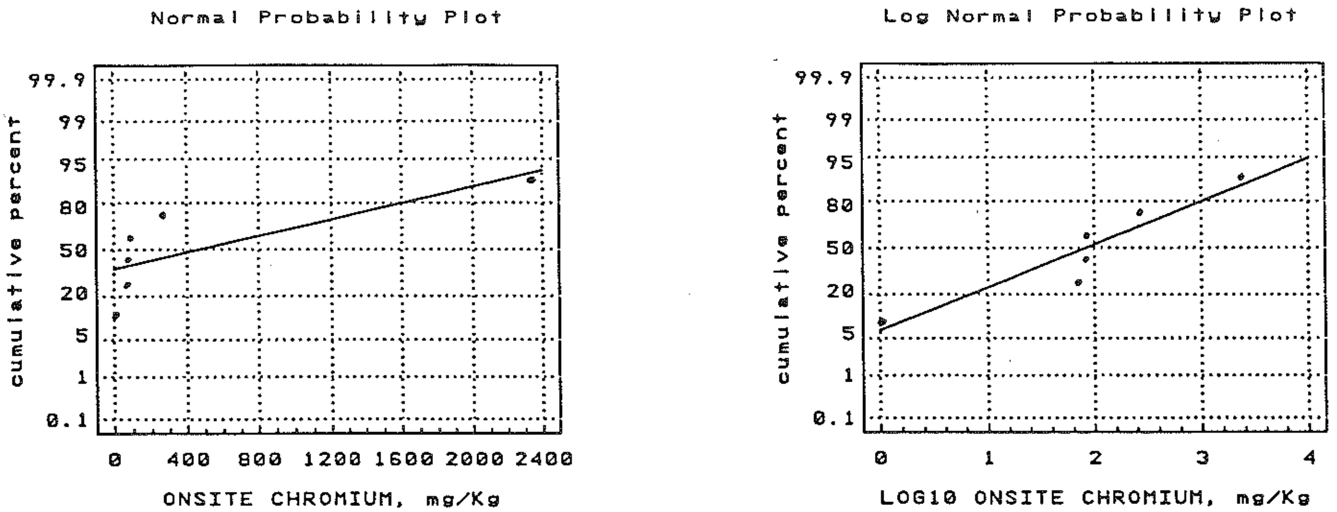


b. OFFSITE BARIUM

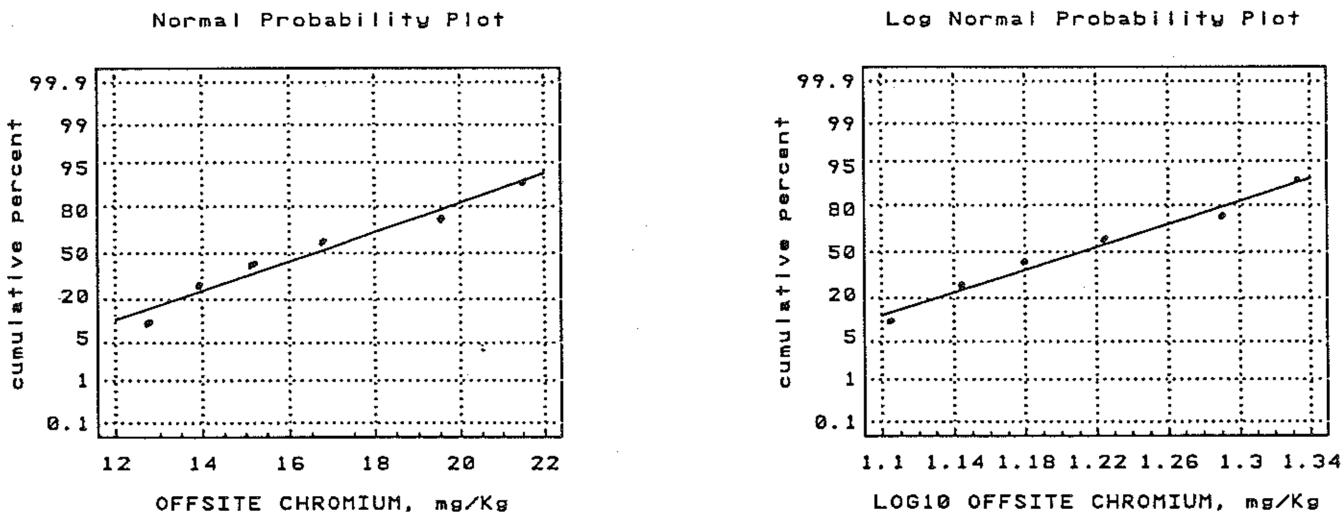


c. ALL DATA

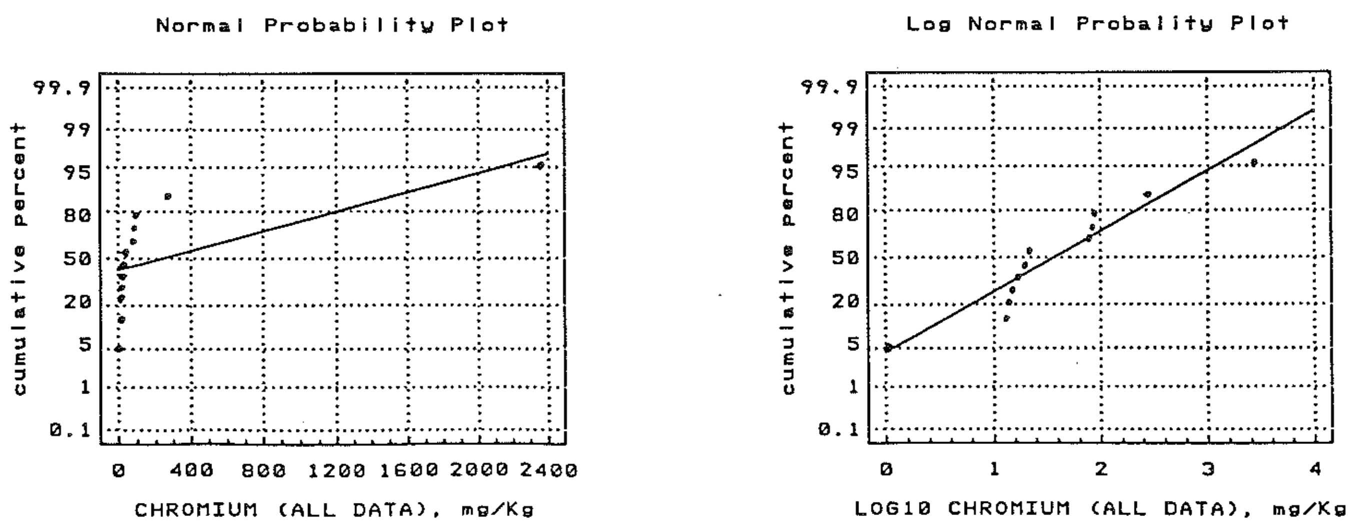
FIGURE 2 - NORMAL AND LOG NORMAL PROBABILITY PLOTS FOR BARIUM



a. ONSITE CHROMIUM

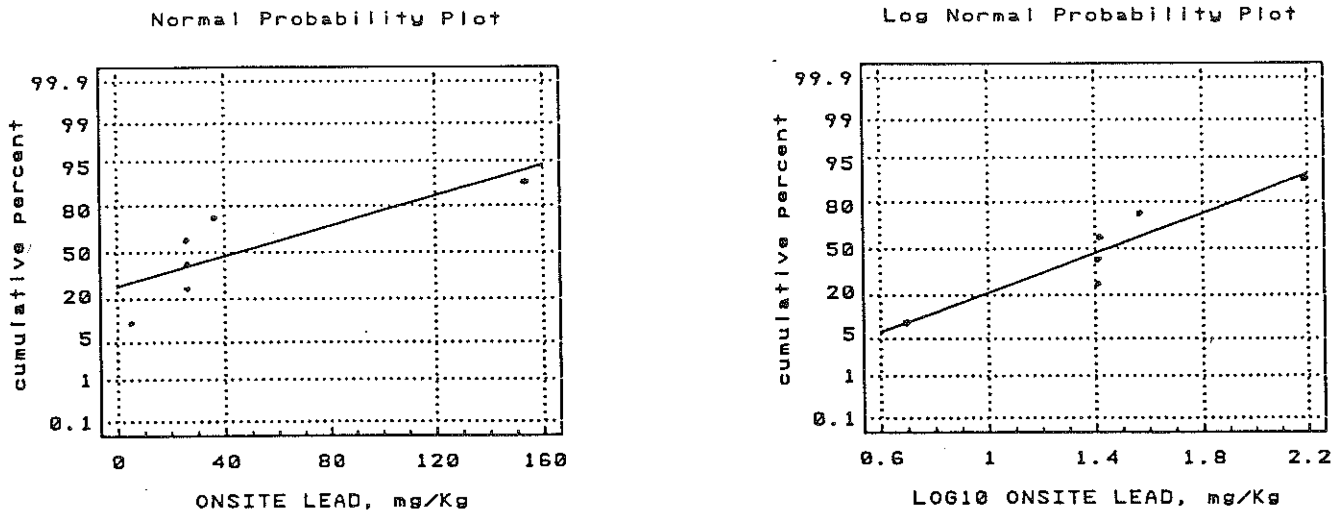


b. OFFSITE CHROMIUM

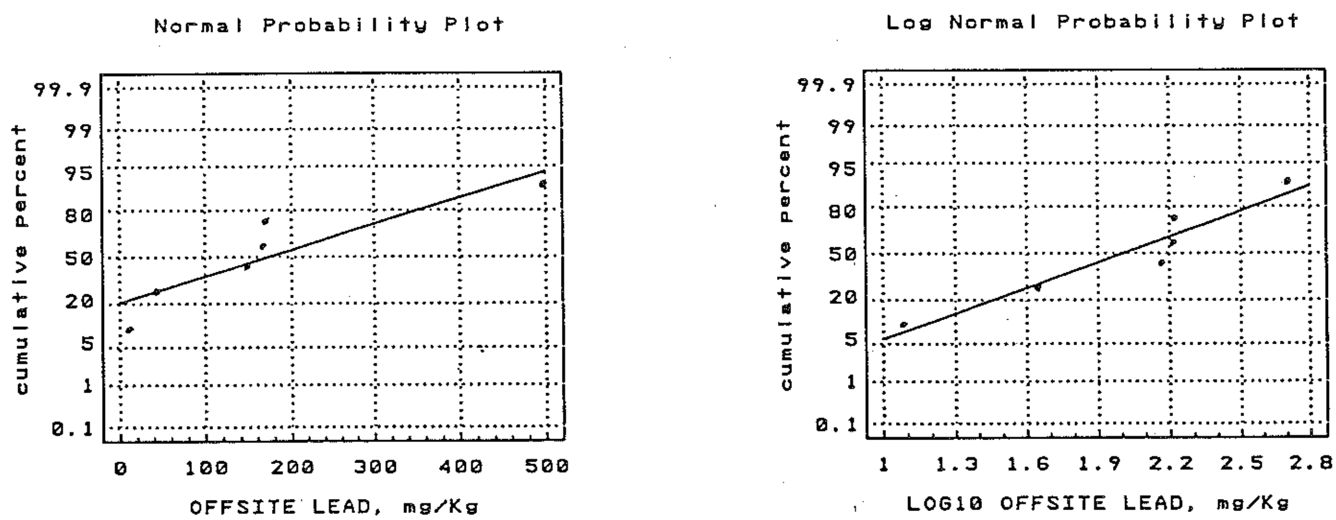


c. ALL DATA

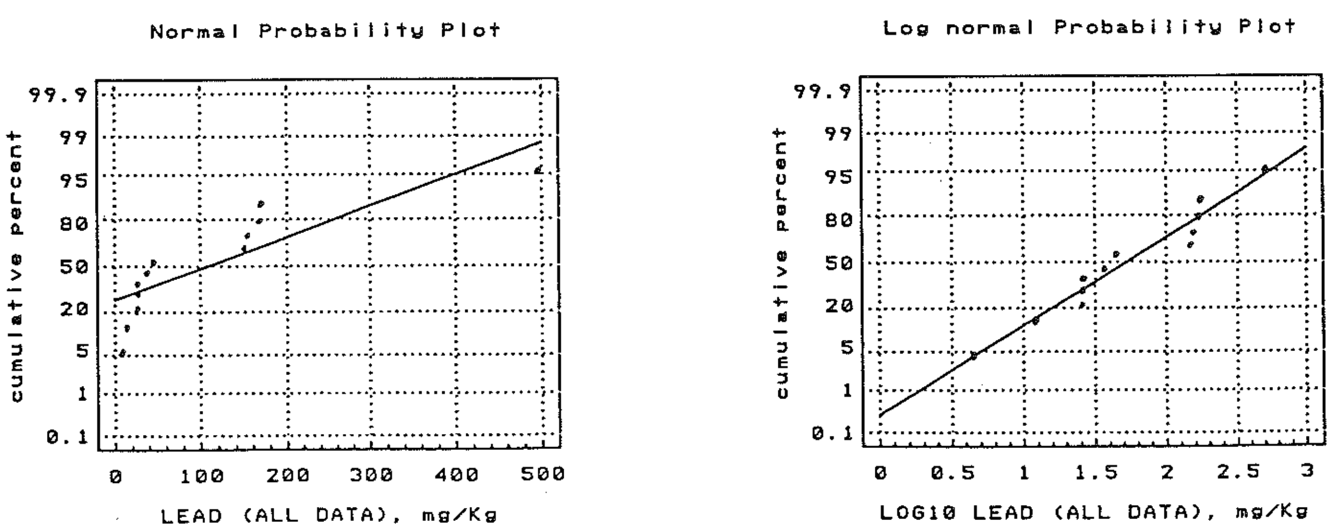
FIGURE 3 - NORMAL AND LOG NORMAL PROBABILITY PLOTS FOR CHROMIUM



a. ONSITE LEAD

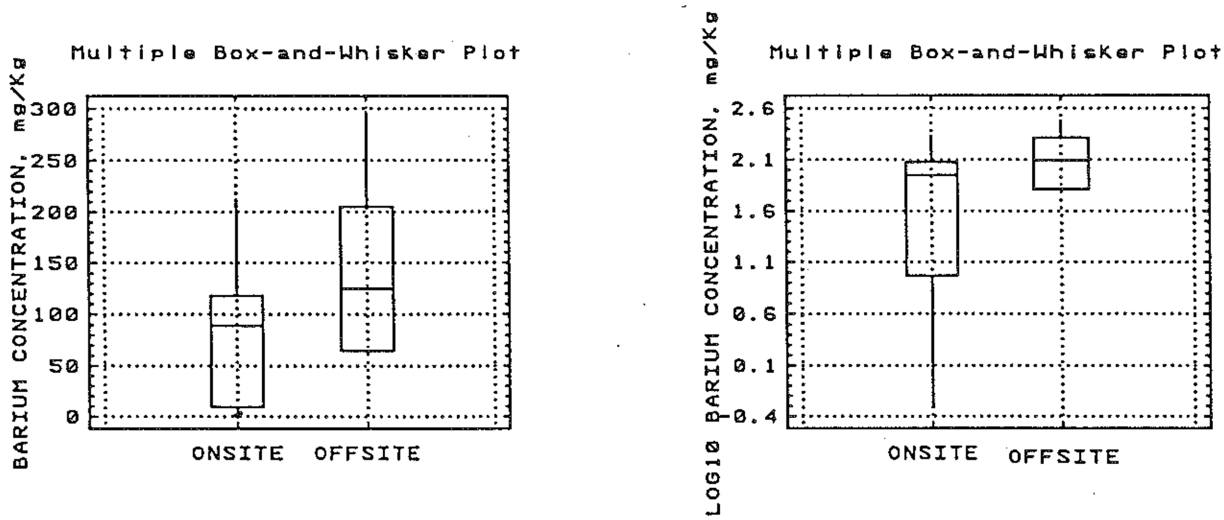


b. OFFSITE LEAD

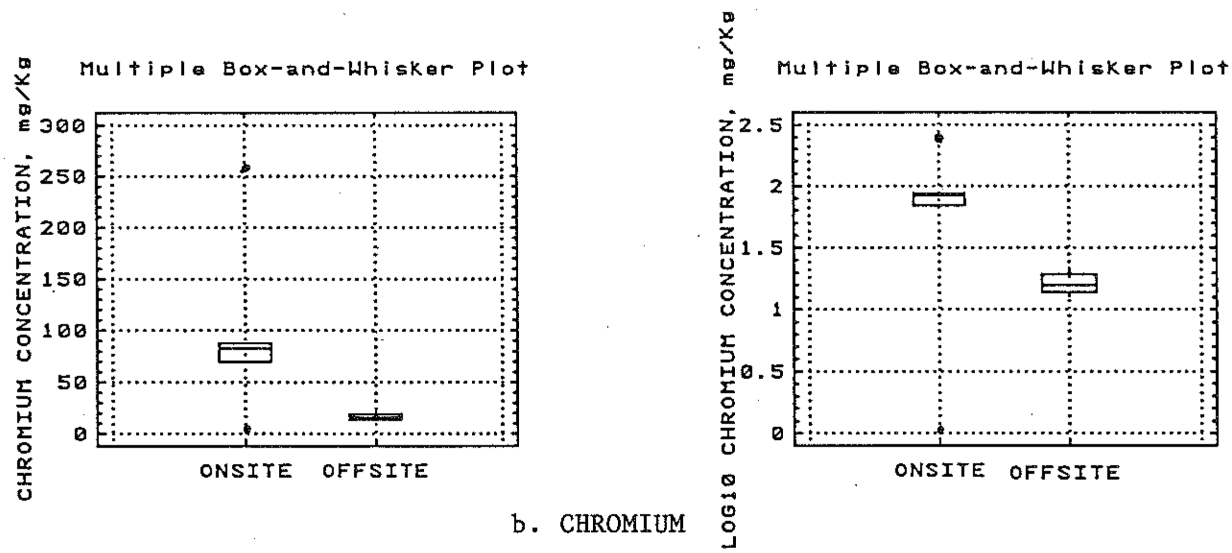


c. ALL DATA

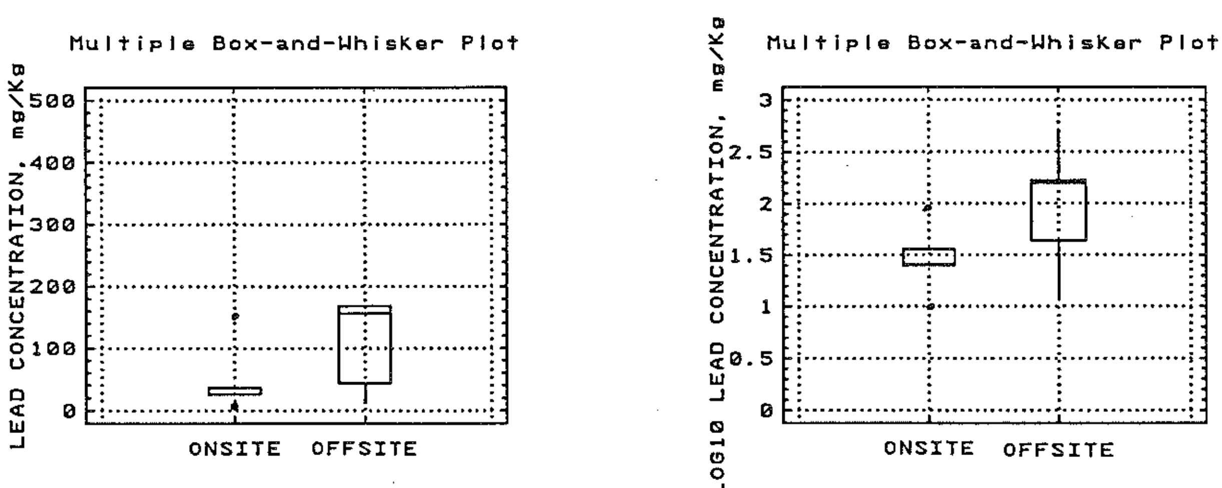
FIGURE 4 - NORMAL AND LOG NORMAL PROBABILITY PLOTS FOR LEAD



a. BARIUM



b. CHROMIUM



c. LEAD

FIGURE 5 - BOX PLOTS OF ON-SITE AND OFF-SITE CONCENTRATIONS
FOR NORMAL AND LOGNORMAL DATA

APPENDIX A

LABORATORY RESULTS

ENSECO-WADSWORTH/ALERT Laboratories
Division of Corning Lab Services, Inc.

Corporate and Laboratory:
4101 Shuffel Drive, NW
North Canton, OH 44720
216-497-9396
FAX 216-497-0772

ANALYTICAL REPORT

PROJECT NO. 2169.15

ASF-ALLIANCE, OH

LYNN HALL

RMT

ENSECO-WADSWORTH/ALERT LABORATORIES

Theresa K. Finley

Theresa K. Finley
Project Manager

Mark P. Nebiolo
Laboratory Manager

September 15, 1993

PROJECT NARRATIVE

The following report contains the analytical results for twelve solid samples and one Quality Control sample submitted to Enseco-Wadsworth/ALERT Laboratories by RMT from the ASF-Alliance, OH Site project number 2169.15. The samples were received August 30, 1993, according to documented sample acceptance procedures.

Enseco-Wadsworth/ALERT Laboratories utilizes only USEPA approved methods and instrumentation in all analytical work. The samples presented in this report were analyzed for the parameters listed on the following page in accordance with the methods indicated. A summary of QC data for these analyses is included at the end of the report.

ANALYTICAL METHODS SUMMARY

Enseco-Wadsworth/ALERT Laboratories utilizes only USEPA approved methods in analytical work. The methods used for the analyses presented in the following report are listed below.

Parameters	Methods
Barium	SW846 6010
Cadmium	SW846 6010
Chromium	SW846 6010
Lead	SW846 6010
Solids, Total (TS)	MCAWW 160.3 MODIFIED

References:

MCAWW Methods for Chemical Analysis of Water and Wastes, EMSL: Cincinnati, OH: March 1983 and its updates.

SW846 "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, September, 1986.

SAMPLE SUMMARY

The analytical results of the samples listed below are presented on the following pages.

WO #	LABORATORY ID	SAMPLE IDENTIFICATION
F6344	A3H300028-001	11 8-30-93 1005
F6345	A3H300028-002	12 8-30-93 1100
F6346	A3H300028-003	09 8-30-93 1115
F6347	A3H300028-004	10 8-30-93 1130
F6348	A3H300028-005	08 8-30-93 1145
F6349	A3H300028-006	07 8-30-93 1200
F6350	A3H300028-007	DUP 8-30-93 1210
F6351	A3H300028-008	03 8-30-93 1220
F6352	A3H300028-009	04 8-30-93 1235
F6353	A3H300028-010	06 8-30-93 1240
F6354	A3H300028-011	05 8-30-93 1250
F6355	A3H300028-012	02 8-30-93 1310
F6356	A3H300028-013	01 8-30-93 1320

RMT

11 8-30-93 1005

WO #: F6344
LAB #: A3H300028-001
MATRIX: SOLID

DATE RECEIVED: 8/30/93

\- REQUESTED METALS -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	9.3	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	69.9	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	25.3	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:
AS RECEIVED
ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

11 8-30-93 1005

WO #: F6344
LAB #: A3H300028-001
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- INORGANIC ANALYTICAL REPORT -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	87.2	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251048

NOTE: AS RECEIVED

RMT

12 8-30-93 1100

WO #: F6345
LAB #: A3H300028-002
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	85.5	5.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	2,330	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	25.7	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

12 8-30-93 1100

WO #: F6345
LAB #: A3H300028-002
MATRIX: SOLID

DATE RECEIVED: 8/30/93

INORGANIC ANALYTICAL REPORT

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	93.8	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251048

NOTE: AS RECEIVED

RMT

09 8-30-93 1115

WO #: F6346
LAB #: A3H300028-003
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	212	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	87.6	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	25.9	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

09 8-30-93 1115

WO #: F6346
LAB #: A3H300028-003
MATRIX: SOLID

DATE RECEIVED: 8/30/93

INORGANIC ANALYTICAL REPORT

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	84.6	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251048

NOTE: AS RECEIVED

RMT

10 8-30-93 1130

WO #: F6347
LAB #: A3H300028-004 **DATE RECEIVED:** 8/30/93
MATRIX: SOLID

- **REQUESTED METALS** -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	92.8	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	260	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	36.3	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:
AS RECEIVED
ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

10 8-30-93 1130

WO #: F6347
LAB #: A3H300028-004
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	89.6	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

08 8-30-93 1145

WO #: F6348
LAB #: A3H300028-005
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- REQUESTED METALS -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	ND	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	ND	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

08 8-30-93 1145

WO #: F6348
LAB #: A3H300028-005
MATRIX: SOLID

DATE RECEIVED: 8/30/93

INORGANIC ANALYTICAL REPORT

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	88.6	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

07 8-30-93 1200

WO #: F6349
LAB #: A3H300028-006 DATE RECEIVED: 8/30/93
MATRIX: SOLID

- - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	119	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	69.3	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	63.6	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:
AS RECEIVED
ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

07 8-30-93 1200

WO #: F6349
LAB #: A3H300028-006
MATRIX: SOLID

DATE RECEIVED: 8/30/93

INORGANIC ANALYTICAL REPORT

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	87.6	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

DUP 8-30-93 1210

WO #: F6350
LAB #: A3H300028-007
MATRIX: SOLID

DATE RECEIVED: 8/30/93

\- - - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	118	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	97.0	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	241	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

DUP 8-30-93 1210

WO #: F6350
LAB #: A3H300028-007
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	91.1	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

03 8-30-93 1220

WO #: F6351
LAB #: A3H300028-008
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	148	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	12.7	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	148	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

03 8-30-93 1220

WO #: F6351
LAB #: A3H300028-008
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	86.3	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

04 8-30-93 1235

WO #: F6352
LAB #: A3H300028-009
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	103	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	16.7	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	16.8	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

04 8-30-93 1235

WO #: F6352
LAB #: A3H300028-009
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	85.6	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

06 8-30-93 1240

WO #: F6353
LAB #: A3H300028-010
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	296	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	19.5	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	498	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

06 8-30-93 1240

WO #: F6353
LAB #: A3H300028-010
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	87.5	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

05 8-30-93 1250

WO #: F6354
LAB #: A3H300028-011
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	61.1	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	15.1	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	12.0	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:
AS RECEIVED
ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

05 8-30-93 1250

WO #: F6354
LAB #: A3H300028-011
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	85.3	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

02 8-30-93 1310

WO #: F6355
LAB #: A3H300028-012 DATE RECEIVED: 8/30/93
MATRIX: SOLID

- - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	64.6	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	13.9	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	43.6	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:

AS RECEIVED

ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

02 8-30-93 1310

WO #: F6355
LAB #: A3H300028-012
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	67.9	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

RMT

01 8-30-93 1320

WO #: F6356
LAB #: A3H300028-013
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - - REQUESTED METALS - - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Barium	205	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Chromium	21.5	2.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008
Lead	165	10.0	mg/kg	SW846 6010	9/08- 9/10/93	3251008

NOTE:
AS RECEIVED
ND NOT DETECTED AT THE STATED REPORTING LIMIT

RMT

01 8-30-93 1320

WO #: F6356
LAB #: A3H300028-013
MATRIX: SOLID

DATE RECEIVED: 8/30/93

- - - - - - - - - - - - - - - - - **INORGANIC ANALYTICAL REPORT** - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	89.8	0.50	%	MCAWW 160.3	9/08- 9/09/93	3251057

NOTE: AS RECEIVED

QUALITY CONTROL SECTION

QUALITY CONTROL NARRATIVE

The results included in this report have been reviewed for compliance with the laboratory QA/QC plan. All data have been found to be compliant with the exception of those items noted.

The matrix spike and matrix spike duplicate (MS/MSD) contained in this quality control report were generated as part of the laboratory QA/QC program requirements. These requirements include the analysis of a MS/MSD on a one in twenty basis. Therefore, the associated batch number indicated on the MS/MSD report may not reflect the same batch number as those of the samples contained in the analytical report.

CHECK SAMPLE REPORT

LAB #: A3H300028

- - - - - - - - - - - - - - - - - - - METALS -

COMPOUND	SPIKE PERCENT RECOVERY	Q/C LIMITS	PREPARATION - ANALYSIS DATE
	BATCH:3251008 MATRIX:	SOLID	
Barium	95	(82-112)	9/08- 9/10/93
Cadmium	89	(72-109)	9/08- 9/10/93
Chromium	94	(76-118)	9/08- 9/10/93
Lead	92	(78-112)	9/08- 9/10/93

CHECK SAMPLE REPORT

LAB #: A3H300028

- - - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - - -

COMPOUND	SPIKE PERCENT RECOVERY	LIMITS	MATRIX	PREPARATION - ANALYSIS DATE	Q/C BATCH
Solids, Total (TS)	98	(89-110)	SOLID	9/08- 9/09/93	3251048
Solids, Total (TS)	102	(89-110)	SOLID	9/08- 9/09/93	3251057

INTRA-LAB BLANK REPORT

LAB #: A3H300028

- METALS -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	METHOD	PREPARATION - ANALYSIS DATE
		BATCH:3251008 MATRIX:SOLID			
Barium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93
Cadmium	ND	1.0	mg/kg	SW846 6010	9/08- 9/10/93
Chromium	ND	2.0	mg/kg	SW846 6010	9/08- 9/10/93
Lead	ND	10.0	mg/kg	SW846 6010	9/08- 9/10/93

NOTE:

ND NOT DETECTED AT THE STATED REPORTING LIMIT

INTRA-LAB BLANK REPORT

LAB #: A3H300028

- - - - - - - - - - - - - - - - - INORGANIC ANALYTICAL REPORT - - - - - - - - - - - - - - - - -

PARAMETER	RESULT	REPORTING LIMIT	UNIT	MATRIX	PREPARATION - ANALYSIS DATE	QC BATCH
Solids, Total (TS)	ND	0.50	%	SOLID	9/08- 9/09/93	3251048
Solids, Total (TS)	ND	0.50	%	SOLID	9/08- 9/09/93	3251057

NOTE:

ND NOT DETECTED AT THE STATED REPORTING LIMIT

MATRIX SPIKE REPORT

SOLID - ICP

\- - - - - - - - - - - - - - - - - - -METALS- - - - - - - - - - - - - - - - - - -

COMPOUND	SPIKE PERCENT RECOVERY	SPIKE/DUP PERCENT RECOVERY	Q/C LIMITS	RPD	RPD LIMITS	PREPARATION-ANALYSIS DATE	W/O#
Silver	87	86	(60-110)	2	(0-20)	7/15-7/25/93	E5241
Aluminum	108	98	(56-138)	10	(0-20)	7/08-7/09/93	E4621
Boron	73	75	(66-122)	3	(0-20)	6/10-6/23/93	D9278
Barium	88	87	(15-151)	2	(0-20)	7/15-7/25/93	E5241
Beryllium	86	87	(68-110)	1	(0-20)	7/15-7/25/93	E5241
Calcium	91	90	(64-126)	1	(0-20)	7/15-7/25/93	E5241
Cadmium	88	86	(65-110)	2	(0-20)	7/15-7/25/93	E5241
Cobalt	91	90	(57-108)	1	(0-20)	7/15-7/25/93	E5241
Chromium	88	86	(56-114)	2	(0-20)	7/15-7/25/93	E5241
Copper	88	91	(62-115)	3	(0-20)	7/18-7/26/93	E6162
Iron	94	79	(59-120)	17	(0-20)	7/15-7/25/93	E5241
Potassium	93	91	(10-170)	2	(0-20)	7/15-7/25/93	E5241
Magnesium	98	93	(66-117)	5	(0-20)	7/15-7/25/93	E5241
Manganese	88	85	(10-184)	4	(0-20)	7/15-7/25/93	E5241
Sodium	92	91	(23-140)	1	(0-20)	7/15-7/25/93	E5241
Nickel	79	79	(57-114)	0	(0-20)	7/15-7/25/93	E5241
Lead	83	86	(36-137)	4	(0-20)	7/15-7/25/93	E5241
Antimony	48	47	(10-125)	3	(0-20)	7/15-7/25/93	E5241
Strontium	90	91	(10-125)	1	(0-20)	6/10-6/23/93	D9278
Tin	83	88	(59-115)	6	(0-20)	6/10-6/23/93	D9278
Titanium	102	101	(80-111)	1	(0-20)	5/04-5/07/93	D0765
Thallium	71	74	(57-116)	4	(0-20)	7/26-7/26/93	E5241
Vanadium	100	99	(66-117)	1	(0-20)	7/15-7/25/93	E5241
Zinc	81	77	(36-130)	5	(0-20)	7/15-7/25/93	E5241
Gold	103	102	(70-130)	1	(0-20)	11/30-12/01/92	A3214
Arsenic	91	94	(50-152)	3	(0-20)	4/19-4/21/93	C7259
Selenium	89	101	(50-110)	13	(0-20)	4/19-4/21/93	C7259
Molybdenum	82	83	(78-114)	1	(0-20)	6/10-6/23/93	D9278

ENSECO-WADSWORTH/ALERT LABORATORIES NO. 3345
DIVISION OF CORNING LAB SERVICES, INC.

CLIENT CODE ______________
QUOTE / SAR NUMBER ______________
Chain-of Custody Record

☒ 1) ENSECO-WADSWORTH/ALERT LABORATORIES
DIVISION OF CORNING LAB SERVICES, INC.
4101 SHUFFEL DR. N.W.
NORTH CANTON, OHIO 44720
PHONE (216) 497-9396 FAX (216) 497-0772

☐ 2) ENSECO-WADSWORTH/ALERT LABORATORIES
DIVISION OF CORNING LAB SERVICES, INC.
450 WILLIAM PITT WAY
PITTSBURGH, PA 15238
PHONE (412) 826-5477 FAX (412) 826-5571

☐ 3) ENSECO-WADSWORTH/ALERT LABORATORIES
DIVISION OF CORNING LAB SERVICES, INC.
5910 BRECKENRIDGE PKWY., STE. H
TAMPA, FL 33610
PHONE (813) 621-0784 FAX (813) 623-6021

PROJ. NO.: 2169.15
PROJECT NAME/LOCATION: ASF - Alliance, OH
SAMPLERS: (Signature) Timothy A. Dye

STA. NO.	DATE	TIME	COMP.	GRAB.	STATION LOCATION	NO. OF CONTAINERS	Total Pb	Total Cd	Total Cr	Total Ba		REMARKS
11	8/30/93	1005		X	11	1	X	X	X	X		
12	8/30/93	1100		X	12	1	X	X	X	X		
09	8/30/93	1115		X	09	1	X	X	X	X		
10	8/30/93	1130		X	10	1	X	X	X	X		
08	8/30/93	1145		X	08	1	X	X	X	X		
07	8/30/93	1200		X	07	1	X	X	X	X		
DUP	8/30/93	1210		X	DUP	1	X	X	X	X		
03	8/30/93	1220		X	03	1	X	X	X	X		
04	8/30/93	1235		X	04	1	X	X	X	X		
06	8/30/93	1240		X	06	1	X	X	X	X		
05	8/30/93	1250		X	05	1	X	X	X	X		
02	8/30/93	1310		X	02	1	X	X	X	X		
01	8/30/93	1320		X	01	1	X	X	X	X		

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Timothy A. Dye	8/30/93 3:20 pm				
Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Relinquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks	
		[signature]	8/30/93 3:20	Client - RMT Residual Mgmt. Tech	

Distribution Original Accompanies Shipment. Copy returned with Report.

FORM 004

APPENDIX B

STATISTICAL WORKSHEETS

Note: The statistical calculations were done using Statgraphics® 6.0 software

SUMMARY STATISTICS

Variable:	ONSITE BARIUM	OFFSITE BARIUM	BaALL
Sample size	6.	6.	12.
Average	86.433333	146.283333	116.358333
Median	89.15	125.5	97.9
Mode	9.3	64.6	85.5
Geometric mean	31.225079	124.089883	62.24722
Variance	6034.150667	8333.497667	7507.66447
Standard deviation	77.679796	91.287993	86.64678
Standard error	31.712644	37.268167	25.012771
Minimum	0.5	61.1	0.5
Maximum	212.	296.	296.
Range	211.5	234.9	295.5
Lower quartile	9.3	64.6	62.85
Upper quartile	118.5	205.	176.5
Interquartile range	109.2	140.4	113.65
Skewness	0.588536	0.912581	0.715375
Standardized skewness	0.588536	0.912581	1.011693
Kurtosis	0.278521	-0.051023	0.20801
Standardized kurtosis	0.139261	-0.025511	0.147085
Coeff. of variation	89.872498	62.404917	74.46547
Sum	518.6	877.7	1396.3

Variable:	ONSITE CHROMIUM	OFFSITE CHROMIUM	CrALL
Sample size	6.	6.	12.
Average	471.941667	16.566667	244.254167
Median	85.375	15.9	20.5
Mode	69.9	13.9	16.7
Geometric mean	82.198167	16.286615	36.588658
Variance	835920.214417	11.434667	436523.401572
Standard deviation	914.286724	3.381518	660.699176
Standard error	373.255992	1.380499	190.727424
Minimum	1.	12.7	1.
Maximum	2330.	21.5	2330.
Range	2329.	8.8	2329.
Lower quartile	69.9	13.9	14.5
Upper quartile	260.	19.5	85.375
Interquartile range	190.1	5.6	70.875
Skewness	2.402379	0.507257	3.394825
Standardized skewness	2.402379	0.507257	4.801008
Kurtosis	5.812259	-1.190279	11.63493
Standardized kurtosis	2.906129	-0.59514	8.227138
Coeff. of variation	193.728757	20.41158	270.496584
Sum	2831.65	99.4	2931.05

Variable:	ONSITE Pb	OFFSITE Pb	PbALL
Sample size	6.	6.	12.
Average	45.083333	172.433333	108.758333
Median	25.8	156.5	39.95
Mode	25.3	43.6	25.9
Geometric mean	27.839087	101.11727	53.056691
Variance	2862.865667	29800.486667	19270.075379
Standard deviation	53.505754	172.628175	138.816697
Standard error	21.843632	70.475157	40.072929
Minimum	5.	12.	5.
Maximum	152.3	498.	498.
Range	147.3	486.	493.
Lower quartile	25.3	43.6	25.5
Upper quartile	36.3	168.	158.65
Interquartile range	11.	124.4	133.15
Skewness	2.243122	1.645973	2.247033
Standardized skewness	2.243122	1.645973	3.177785
Kurtosis	5.293821	3.345086	5.886096
Standardized kurtosis	2.64691	1.672543	4.162099
Coeff. of variation	118.681893	100.112995	127.637757
Sum	270.5	1034.6	1305.1

Variable:	ONSITE CHROMIUM (OUTLIER REMOVED)	ALL CHROMIUM (OUTLIER REMOVED)
Sample size	5.	11.
Average	100.33	54.640909
Median	83.15	19.5
Mode	69.9	16.7
Geometric mean	42.10788	25.081045
Variance	9186.037	5593.667409
Standard deviation	95.843816	74.790824
Standard error	42.862657	22.550282
Minimum	1.	1.
Maximum	260.	260.
Range	259.	259.
Lower quartile	69.9	13.9
Upper quartile	87.6	83.15
Interquartile range	17.7	69.25
Skewness	1.44597	2.404692
Standardized skewness	1.319984	3.255968
Kurtosis	3.084655	6.390554
Standardized kurtosis	1.407946	4.326426
Coeff. of variation	95.528571	136.876977
Sum	501.65	601.05

Variable:	LOG 10 ONSITE Ba	LOG 10 OFFSITE Ba	LOG 10 Ba-ALL DATA
Sample size	6.	6.	12.
Average	1.494504	2.093736	1.79412
Median	1.949757	2.091549	1.990193
Mode	0.968483	1.810233	1.931966
Geometric mean		2.078749	
Variance	0.988644	0.075506	0.581635
Standard deviation	0.994306	0.274784	0.76265
Standard error	0.405924	0.11218	0.220158
Minimum	-0.30103	1.786041	-0.30103
Maximum	2.326336	2.471292	2.471292
Range	2.627366	0.685251	2.772322
Lower quartile	0.968483	1.810233	1.798137
Upper quartile	2.073718	2.311754	2.241008
Interquartile range	1.105235	0.501521	0.442871
Skewness	-1.518219	0.176161	-2.229716
Standardized skewness	-1.518219	0.176161	-3.153294
Kurtosis	1.73419	-1.57449	5.340979
Standardized kurtosis	0.867095	-0.787245	3.776642
Coeff. of variation	66.530826	13.124097	42.508318
Sum	8.967021	12.562418	21.529439

Variable:	LOG 10 ONSITE Cr	LOG 10 OFFSITE Cr	LOG 10 ALL Cr
Sample size	6.	6.	12.
Average	1.914862	1.211831	1.563346
Median	1.931183	1.200847	1.311237
Mode	1.844477	1.143015	1.222716
Geometric mean		1.209216	
Variance	1.206458	0.007653	0.686665
Standard deviation	1.098389	0.087482	0.828652
Standard error	0.448415	0.035714	0.239211
Minimum	0.	1.103804	0.
Maximum	3.367356	1.332438	3.367356
Range	3.367356	0.228635	3.367356
Lower quartile	1.844477	1.143015	1.160996
Upper quartile	2.414973	1.290035	1.931183
Interquartile range	0.570496	0.14702	0.770187
Skewness	-0.867536	0.274206	0.477293
Standardized skewness	-0.867536	0.274206	0.674994
Kurtosis	2.386495	-1.364358	1.732678
Standardized kurtosis	1.193248	-0.682179	1.225188
Coeff. of variation	57.361246	7.218986	53.005042
Sum	11.489173	7.270985	18.760158

Variable:	LOG 10 ONSITE Pb	LOG 10 OFFSITE Pb	LOG 10 ALL Pb
Sample size	6.	6.	12.
Average	1.444655	2.004825	1.72474
Median	1.411616	2.193873	1.599697
Mode	1.403121	1.639486	1.4133
Geometric mean	1.37145	1.926403	1.625412
Variance	0.223591	0.318184	0.33184
Standard deviation	0.472854	0.564078	0.576056
Standard error	0.193042	0.230284	0.166293
Minimum	0.69897	1.079181	0.69897
Maximum	2.1827	2.697229	2.697229
Range	1.48373	1.618048	1.998259
Lower quartile	1.403121	1.639486	1.406527
Upper quartile	1.559907	2.225309	2.200092
Interquartile range	0.156786	0.585823	0.793565
Skewness	-0.03186	-0.810761	-0.056422
Standardized skewness	-0.03186	-0.810761	-0.079793
Kurtosis	2.236324	0.574002	-0.583168
Standardized kurtosis	1.118162	0.287001	-0.412362
Coeff. of variation	32.731256	28.136007	33.399576
Sum	8.66793	12.028952	20.696882

Variable:	LOG 10 ONSITE Cr (OUTLIER REMOVED)	LOG 10 Cr (OUTLIER REMOVED)
Sample size	5.	11.
Average	1.624363	1.399346
Median	1.919862	1.290035
Mode	1.844477	1.222716
Geometric mean		
Variance	0.875151	0.4003
Standard deviation	0.935495	0.632693
Standard error	0.418366	0.190764
Minimum	0.	0.
Maximum	2.414973	2.414973
Range	2.414973	2.414973
Lower quartile	1.844477	1.143015
Upper quartile	1.942504	1.919862
Interquartile range	0.098027	0.776847
Skewness	-1.894837	-0.658019
Standardized skewness	-1.729742	-0.890962
Kurtosis	4.033238	1.683828
Standardized kurtosis	1.840913	1.139957
Coeff. of variation	57.591487	45.213493
Sum	8.121817	15.392802

KOLMOGOROV STATISTICS

ONSITE BARIUM - K-S STATISTIC - NORMAL DISTRIBUTION

Estimated KOLMOGOROV statistic DPLUS = 0.173206
Estimated KOLMOGOROV statistic DMINUS = 0.161871
Estimated overall statistic DN = 0.173206
Approximate significance level = 0.993764

ONSITE LOG10 BARIUM - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.201409
Estimated KOLMOGOROV statistic DMINUS = 0.336688
Estimated overall statistic DN = 0.336688
Approximate significance level = 0.504506

OFFSITE BARIUM - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.1823
Estimated KOLMOGOROV statistic DMINUS = 0.175377
Estimated overall statistic DN = 0.1823
Approximate significance level = 0.988459

OFFSITE BARIUM - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.182239
Estimated KOLMOGOROV statistic DMINUS = 0.131402
Estimated overall statistic DN = 0.182239
Approximate significance level = 0.988504

BARIUM - ALL DATA - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.156803
Estimated KOLMOGOROV statistic DMINUS = 0.0968531
Estimated overall statistic DN = 0.156803
Approximate significance level = 0.929501

BARIUM - ALL DATA - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.187291
Estimated KOLMOGOROV statistic DMINUS = 0.329105
Estimated overall statistic DN = 0.329105
Approximate significance level = 0.14857

ONSITE CR. - K-S STATISTIC NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.424993
Estimated KOLMOGOROV statistic DMINUS = 0.303243
Estimated overall statistic DN = 0.424993
Approximate significance level = 0.228599

ON SITE CR - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.157773
Estimated KOLMOGOROV statistic DMINUS = 0.307785
Estimated overall statistic DN = 0.307785
Approximate significance level = 0.62058

OFFSITE CR - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.146373
Estimated KOLMOGOROV statistic DMINUS = 0.14766
Estimated overall statistic DN = 0.14766
Approximate significance level = 0.999444

OFF SITE CR - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.167763
Estimated KOLMOGOROV statistic DMINUS = 0.140487
Estimated overall statistic DN = 0.167763
Approximate significance level = 0.995903

CR. ALL DATA - K-S STATISTIC NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.427047
Estimated KOLMOGOROV statistic DMINUS = 0.356369
Estimated overall statistic DN = 0.427047
Approximate significance level = 0.0251294

CR - ALL DATA - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.193082
Estimated KOLMOGOROV statistic DMINUS = 0.206259
Estimated overall statistic DN = 0.206259
Approximate significance level = 0.686976

ONSITE Pb - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.398532
Estimated KOLMOGOROV statistic DMINUS = 0.226885
Estimated overall statistic DN = 0.398532
Approximate significance level = 0.296391

ONSITE Pb - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.237045
Estimated KOLMOGOROV statistic DMINUS = 0.298338
Estimated overall statistic DN = 0.298338
Approximate significance level = 0.65958

OFFSITE Pb - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.34358
Estimated KOLMOGOROV statistic DMINUS = 0.176351
Estimated overall statistic DN = 0.34358
Approximate significance level = 0.478176

OFFSITE Pb - K-S STATISTIC - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.181279
Estimated KOLMOGOROV statistic DMINUS = 0.282014
Estimated overall statistic DN = 0.282014
Approximate significance level = 0.726508

Pb - ALL DATA - K-S STATISTIC - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.263936
Estimated KOLMOGOROV statistic DMINUS = 0.227397
Estimated overall statistic DN = 0.263936
Approximate significance level = 0.373289

Pb - ALL DATA KOLMOGOROV STAT. - LOG NORMAL DIST'N.

Estimated KOLMOGOROV statistic DPLUS = 0.142163
Estimated KOLMOGOROV statistic DMINUS = 0.197025
Estimated overall statistic DN = 0.197025
Approximate significance level = 0.740112

CR - ONSITE - OUTLIER REMOVED - NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.352835
Estimated KOLMOGOROV statistic DMINUS = 0.175432
Estimated overall statistic DN = 0.352835
Approximate significance level = 0.562201

CR - ONSITE - OUTLIER REMOVED - LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.199019
Estimated KOLMOGOROV statistic DMINUS = 0.393012
Estimated overall statistic DN = 0.393012
Approximate significance level = 0.422654

CHROMIUM - ALL DATA (OUTLIER REMOVED) NORMAL DIST'N.

Estimated KOLMOGOROV statistic DPLUS = 0.307524
Estimated KOLMOGOROV statistic DMINUS = 0.23662
Estimated overall statistic DN = 0.307524
Approximate significance level = 0.249234

CR - ALL DATA (OUTLIER REMOVED) LOG NORMAL DIST'N

Estimated KOLMOGOROV statistic DPLUS = 0.178479
Estimated KOLMOGOROV statistic DMINUS = 0.229295
Estimated overall statistic DN = 0.229295
Approximate significance level = 0.609547

APPENDIX C

REFERENCES

REFERENCE ON K-S TEST
FOR GOODNESS OF FIT

CHAPTER 6

Statistics of the Kolmogorov–Smirnov Type

PRELIMINARY REMARKS

In Chapter 2 the empirical distribution function was introduced as a function based on a random sample that may be used to estimate the true distribution function of the population. If we want to see if two or more samples are governed by the same unknown distribution, it seems natural to compare the empirical distribution functions of those samples to see if they look somewhat similar. To be precise, however, some measure of disparity between or among these functions is needed. Kolmogorov and Smirnov developed statistical procedures that use the maximum vertical distance between these functions as a measure of how well the functions resemble each other. Their methods and other methods that use the same idea are presented in this chapter.

6.1. THE KOLMOGOROV GOODNESS-OF-FIT TEST

We will begin this chapter with a test for goodness of fit that was introduced by Kolmogorov (1933). This test is perhaps the most useful of the tests in this chapter, partly because it furnishes us with an alternative, designed for ordinal data, to the chi-square test for goodness of fit introduced in Section 4.5, which was designed for nominal type data, and partly because the Kolmogorov test statistic enables us to form a "confidence band" for the unknown distribution function, as we will explain in this section.

A test for goodness of fit usually involves examining a random sample from some unknown distribution in order to test the null hypothesis that the unknown distribution function is in fact a known, specified function. That is, the null hypothesis specifies some distribution function $F^*(x)$, perhaps graphically as in Figure 1, or perhaps as a mathematical function that may be graphed. A random sample $X_1, X_2, \ldots, X_n$ is then drawn from some population and is compared with $F^*(x)$ in some way to see if it is reasonable to say that $F^*(x)$ is the true distribution function of the random sample.

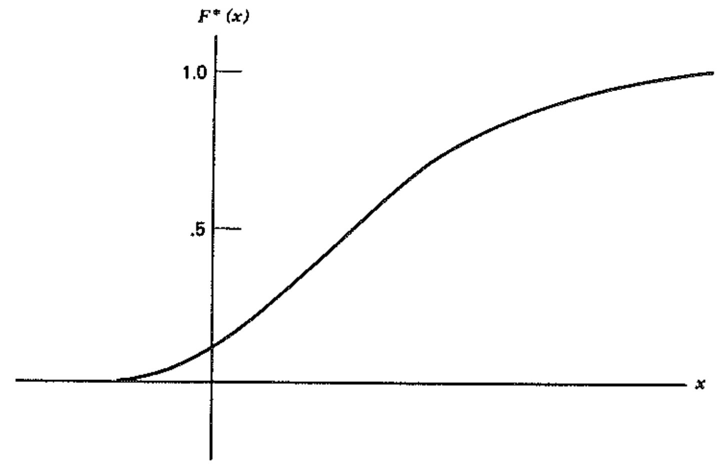


Figure 1. A hypothesized distribution function.

One logical way of comparing the random sample with $F^*(x)$ is by means of the empirical distribution function $S(x)$, which was defined by Definition 2.2.1 as the fraction of X_is that are less than or equal to x for each x, $-\infty < x < +\infty$. We learned in Section 2.2 that the empirical distribution function $S(x)$ is useful as an estimator of $F(x)$, the unknown distribution function of the X_is. So we can compare the empirical distribution function $S(x)$ with the hypothesized distribution function $F^*(x)$ to see if there is good agreement. If there is not good agreement, then we may reject the null hypothesis and conclude that the true but unknown distribution function, $F(x)$, is in fact not given by the function $F^*(x)$ in the null hypothesis.

But what sort of test statistic can we use as a measure of the discrepancy between $S(x)$ *and* $F^*(x)$? One of the simplest measures imaginable is the largest distance between the two graphs $S(x)$ and $F(x)$, measured in a vertical direction. This is the statistic suggested by Kolmogorov (1933). That is, if $F^*(x)$ is given by Figure 1 and a random sample of size 5 is drawn from the population, the empirical distribution function $S(x)$ may be drawn on the same graph along with $F^*(x)$, as shown in Figure 2. If $F^*(x)$ and $S(x)$ are as given the maximum vertical distance between the two graphs occurs just before the third step of $S(x)$. This distance is about 0.5 in Figure 2; therefore the Kolmogorov statistic T equals 0.5 in this case. Large values of T as determined by Table A14 lead to rejection of $F^*(x)$ as a reasonable approximation to the unknown true distribution function $F(x)$.

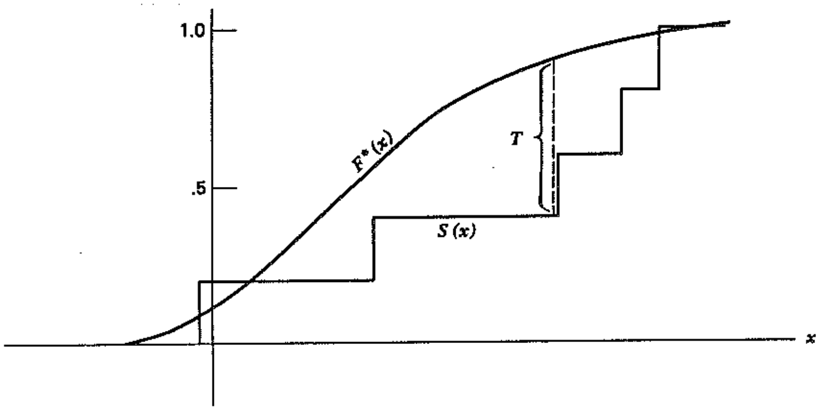


Figure 2. The hypothesized distribution function $F^*(x)$, the empirical distribution function $S(x)$, and Kolmogorov's statistic T.

The Kolmogorov test may be preferred over the chi-square test for goodness of fit if the sample size is small; the Kolmogorov test is exact even for small samples, while the chi-square test assumes that the number of observations is large enough so that the chi-square distribution provides a good approximation as the distribution of the test statistic. There is controversy over which test is the more powerful, but the general feeling seems to be that the Kolmogorov test is probably more powerful than the chi-square test in most situations. For further comparisons see a paper by Slakter (1965).

The title of this chapter is "Statistics of the Kolmogorov–Smirnov Type." Statistics that are functions of the maximum vertical distance between $S(x)$ and $F^*(x)$ are considered to be Kolmogorov-type statistics. Statistics that are functions of the maximum vertical distance between two empirical distribution functions are of the Smirnov type. This entire chapter is concerned with statistics that are determined only by the vertical distances between distribution functions, either hypothesized or empirical distribution functions.

The Kolmogorov Goodness-of-Fit Test

DATA. The data consist of a random sample $X_1, X_2, \ldots, X_n$ of size n associated with some unknown distribution function, denoted by $F(x)$.

ASSUMPTIONS

1. The sample is a random sample.

HYPOTHESES. Let $F^*(x)$ be a completely specified hypothesized distribution function.

A. (Two-Sided Test)

H_0: $F(x) = F^*(x)$ for all x from $-\infty$ to $+\infty$
H_1: $F(x) \neq F^*(x)$ for at least one value of x

B. (One-Sided Test)

H_0: $F(x) \geq F^*(x)$ for all x from $-\infty$ to $+\infty$
H_1: $F(x) < F^*(x)$ for all least one value of x

C. (One-Sided Test)

H_0: $F(x) \leq F^*(x)$ for all x from $-\infty$ to $+\infty$
H_1: $F(x) > F^*(x)$ for at least one value of x

TEST STATISTIC. Let $S(x)$ be the empirical distribution function based on the random sample $X_1, X_2, \ldots, X_n$. The test statistic is defined differently for the three different sets of hypotheses, A, B, and C.

A. (Two-Sided Test) Let the test statistic T be the greatest (denoted by "sup" for supremum) vertical distance between $S(x)$ and $F^*(x)$. In symbols we say

(1) $$T = \sup_x |F^*(x) - S(x)|$$

which is read "T equals the supremum, over all x, of the absolute value of the difference $F^*(x) - S(x)$."

B. (One-Sided Test) Denote this test statistic by T^+ and let it equal the greatest vertical distance attained by $F^*(x)$ above $S(x)$. That is,

(2) $$T^+ = \sup_x [F^*(x) - S(x)]$$

which is similar to T except that we consider only the greatest difference where the function $F^*(x)$ is above the function $S(x)$.

C. (One-Sided Test) For this test use the test statistic T^-, defined as the greatest vertical distance attained by $S(x)$ above $F^*(x)$. Formally this becomes

(3) $$T^- = \sup_x [S(x) - F^*(x)]$$

DECISION RULE. Reject H_0 at the level of significance α if the appropriate test statistic, T, T^+, or T^- exceeds the $1-\alpha$ quantile $w_{1-\alpha}$ as given by Table A14. This table is exact only if $F^*(x)$ is continuous; otherwise these quantiles lead to a conservative test (Noether, 1967a). For a method of finding the exact critical level when $F^*(x)$ is discrete, see the instructions following Example 1.

Quantiles are provided for use in two-sided tests at $\alpha = .20, .10, .05, .02$, and $.01$ and for one-sided tests at α values of $.10, .05, .025, .01$, and $.005$. The tables are exact for $n \leq 20$ in the two-sided test. For the one-sided test and for

$n>20$ in the two-sided test, the tables provide good approximations that are exact in most cases. The approximation for $n>40$ is based on the asymptotic distribution of the test statistics and is not very accurate until n becomes large.

Example 1. A random sample of size 10 is obtained: $X_1=0.621$, $X_2=0.503$, $X_3=0.203$, $X_4=0.477$, $X_5=0.710$, $X_6=0.581$, $X_7=0.329$, $X_8=0.480$, $X_9=0.554$, $X_{10}=0.382$. The null hypothesis is that the distribution function is the uniform distribution function whose graph is given in Figure 3. The mathematical expression for the hypothesized distribution function is

$$(4)\qquad \begin{aligned} F^*(x)&=0 && \text{if} && x<0\\ &=x && \text{if} && 0\le x<1\\ &=1 && \text{if} && 1\le x \end{aligned}$$

Formally, the hypotheses are given by

$$H_0\colon F(x)=F^*(x) \qquad \text{for all } x$$
$$H_1\colon F(x)\ne F^*(x) \qquad \text{for at least one } x$$

where $F(x)$ is the unknown distribution function common to the X_is and $F^*(x)$ is given by Equation 4.

The two-sided Kolmogorov test for goodness of fit is used. The critical region of size $\alpha=0.05$ corresponds to values of T greater than the .95 quantile 0.409, obtained from Table A14 for $n=10$. The value of T is obtained by graphing the empirical distribution function $S(x)$ on top of the hypothesized distribution function $F^*(x)$, as shown in Figure 4. The largest vertical distance separating the two graphs in Figure 4 is 0.290, which occurs at $x=0.710$ because $S(0.710)=1.000$ and $F^*(0.710)=0.710$. In other words,

$$\begin{aligned} T&=\sup_x |F^*(x)-S(x)|\\ &=|F^*(0.710)-S(0.710)|\\ &=0.290 \end{aligned}$$

Since $T=0.290$ is less than 0.409, the null hypothesis is accepted. The critical level $\hat{\alpha}$ is seen, from Table A14, to be somewhat larger than .20.

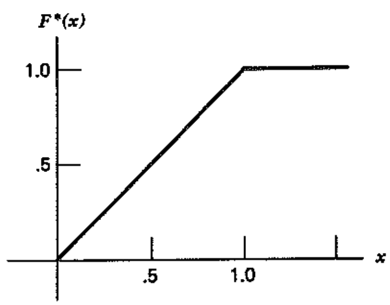


Figure 3. The hypothesized distribution function.

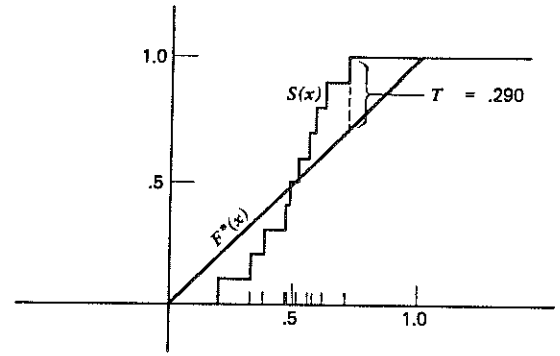


Figure 4. Graphs of $F^*(x)$ and $S(x)$, with T.

If we had wished to test the null hypothesis

$$H_0\colon F(x)\ge F^*(x) \qquad \text{for all } x$$

against the one-sided alternative

$$H_1\colon F(x)<F^*(x) \qquad \text{for some } x$$

the test statistic T^+ would have been used. The decision rule is to reject H_0 at $\alpha=0.05$ if T^+ exceeds the .95 quantile for a one-sided test, 0.369, as given by Table A14 for $n=10$. The value for T^+ in this case is computed just to the left of the second jump of $S(x)$.

$$\begin{aligned} T^+&=\sup_x [F^*(x)-S(x)]\\ &=F^*(0.3289)-S(0.3289)\\ &=0.3289-0.100\\ &=0.2289 \end{aligned}$$

To be more precise, we should say that $T^+=0.228999\ldots$, which is rounded off to 0.229. The end result is the same.

A one-sided test in the other direction would have resulted in

$$\begin{aligned} T^-&=\sup_x [S(x)-F^*(x)]\\ &=S(0.710)-F^*(0.710)\\ &=1.000-0.710\\ &=0.290 \end{aligned}$$

The two-sided test is the appropriate test for this situation. The one-sided tests were presented merely to show how their test statistics are evaluated. In general, of course, the two-sided test statistic T always equals the larger of the two one-sided test statistics T^+ and T^-.

A METHOD OF OBTAINING THE EXACT CRITICAL LEVEL WHEN $F^*(x)$ IS DISCRETE. If the hypothesized distribution function $F^*(x)$ is discrete and the conservative approximation for the critical level obtained from Table A14 is not satisfactory, the exact critical level may be obtained for a particular observed value of the test statistic. This computational procedure may be accomplished by hand for sample sizes of about 5 or less. A computer is recommended for larger sample sizes. For sample sizes larger than 30 or 40 the calculations become tricky, even on a computer. The labor may prove worthwhile, however, because the exact critical values for discrete distributions are often only about one-third as large as their approximations from Table A14.

A. (Two-Sided Test) Let t be the observed value of the test statistic T. Compute $P(T^+ \geq t)$ and $P(T^- \geq t)$ as described in parts B and C that follow, using t instead of t^+ and t^-. Then

$$P(T \geq t) \doteq P(T^+ \geq t) + P(T^- \geq t) \tag{5}$$

is an approximation that is very close to the true critical level in most cases, unless t is small. The error is on the conservative side.

B. (One-Sided Test) Let t^+ denote the observed value of T^+.

Step 1. Compute the probabilities f_j for $0 \leq j < n(1-t^+)$ by drawing a horizontal line with ordinate $1-t^+-j/n$ directly on a graph of $F^*(x)$. Then $f_j = 1-t^+-j/n$ unless the horizontal line intersects $F^*(x)$ at a jump, in which case f_j equals the height of $F^*(x)$ at the bottom of the jump. One of the horizontal lines may intersect $F^*(x)$ directly at the top of a jump; in this event f_j equals the ordinate of the horizontal line.

Step 2. Compute the constants $e_0, e_1, \ldots,$ from the recursive relationship $e_0 = 1$ and

$$e_k = 1 - \sum_{j=0}^{k-1} \binom{k}{j} f_j^{k-j} e_j \qquad k \geq 1 \tag{6}$$

for all k such that $f_k > 0$ in Step 1. Note that these constants are of the form

$$\begin{aligned}
e_0 &= 1\\
e_1 &= 1 - f_0\\
e_2 &= 1 - f_0^2 - 2f_1e_1\\
e_3 &= 1 - f_0^3 - 3f_1^2e_1 - 3f_2e_2\\
e_4 &= 1 - f_0^4 - 4f_1^3e_1 - 6f_2^2e_2 - 4f_3e_3\\
e_5 &= 1 - f_0^5 - 5f_1^4e_1 - 10f_2^3e_2 - 10f_3^2e_3 - 5f_4e_4
\end{aligned}$$

etc.

Step 3. Compute the critical level

$$P(T^+ \geq t^+) = \sum_{j=0}^{[n(1-t^+)]} \binom{n}{j} f_j^{n-j} e_j \tag{7}$$

from the f_j and e_j of Steps 1 and 2.

C. (One-Sided Test) Let t^- denote the observed value of T^-.

Step 1. Compute the probabilities c_j for $0 \leq j < n(1-t^-)$ as follows. Draw a horizontal line with the ordinate $t^- + j/n$ directly on a graph of $F^*(x)$. Then $c_j = 1 - t^- - j/n$ unless the horizontal line intersects $F^*(x)$ at a jump of $F^*(x)$. In that case $c_j = 1.0$ minus the height of $F^*(x)$ at the top of the jump. One of the horizontal lines may intersect $F^*(x)$ exactly at the bottom of a jump, in which event $c_j = 1.0$ minus the ordinate of that line.

Step 2. Compute the constants $b_0, b_1, \ldots,$ from the recursive relationship $b_0 = 1$ and

$$b_k = 1 - \sum_{j=0}^{k-1} \binom{k}{j} c_j^{k-1} b_j \qquad k \geq 1 \tag{8}$$

for all k such that $c_k > 0$ in Step 1. These constants follow the same pattern as the e_ks in part B, with the f_js replaced by c_js.

Step 3. Compute the critical level

$$P(T^- \geq t^-) = \sum_{j=0}^{[n(1-t^-)]} \binom{n}{j} c_j^{n-j} b_j \tag{9}$$

from the c_j and b_j of Steps 1 and 2.

The following example illustrates the method of computing the exact critical level when $F^*(x)$ is discrete.

Example 2. Let $F^*(x)$ be the discrete uniform distribution with equal probabilities 1/5 at the five points $x = 1, 2, 3, 4, 5$. Suppose a random sample of size 10 with the (ordered) values 1, 1, 1, 2, 2, 2, 3, 3, 3, 3, is drawn from some population and the null hypothesis is that $F^*(x)$ is the population distribution function. The greatest distance between $F^*(x)$ and $S(x)$ occurs at $x = 3$ (see Figure 5), so the test statistic for the two-sided Kolmogorov test becomes

$$T = \sup_x |F^*(x) - S(x)| = 0.4 = t \tag{10}$$

To find the critical level associated with $t = 0.4$ the probability $P(T^+ \geq 0.4)$ is computed.

Step 1. Because $n(1-t) = 10(.6) = 6$, the probabilities f_0 to f_5 need to be computed. The horizontal line with ordinate $1 - t = 0.6$ intersects $F^*(x)$ directly at the top of the jump at $x = 3$, so f_0 equals the ordinate of the

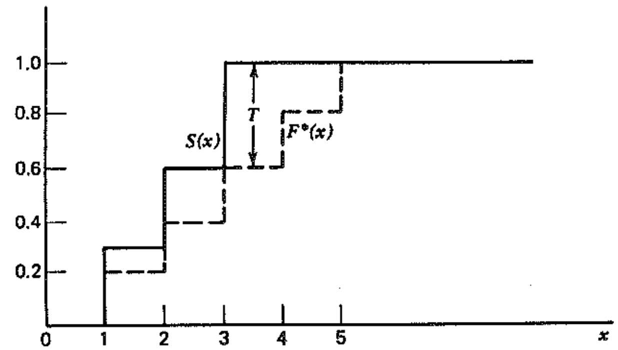


Figure 5. Graphs of $F^*(x)$ and $S(x)$, with T.

horizontal line: $f_0=0.6$. For $j=1$, the horizontal line $1-t-1/10=0.5$ intersects $F^*(x)$ at a jump, so f_1 equals the height of $F^*(x)$ at the bottom of the jump: $f_1=0.4$. Similarly, we find $f_2=0.4$, $f_3=0.2$, $f_4=0.2$, and $f_5=0$.

Step 2. The constants e_0 to e_4 are computed from Equation 6.

$$e_0=1$$
$$e_1=1-0.6=0.4$$
$$e_2=1-(0.6)^2-2(0.4)(0.4)=0.32$$
$$e_3=1-(0.6)^3-3(0.4)^2(0.4)-3(0.4)(0.32)=0.208$$
$$e_4=1-(0.6)^4-4(0.4)^3(0.4)-6(0.4)^2(0.32)-4(0.2)(0.208)=0.2944$$

Step 3. The one-sided critical level $P(T^+\geq t)$ is computed from Equation 7.

$$P(T^+\geq t)=f_0^{10}+\binom{10}{1}f_1^{9}e_1+\binom{10}{2}f_2^{8}e_2+\binom{10}{3}f_3^{7}e_3+\binom{10}{4}f_4^{6}e_4$$

$$=.02081 \tag{11}$$

Because $F^*(x)$ is symmetric, computation of the other one-sided critical level $P(T^-\geq 0.4)$ is identical with the preceding, so $P(T^-\geq 0.4)=.02081$ and the critical level for the two-sided Kolomogorov test is approximately

$$P(T\geq 0.4)\doteq 2(.02081)=.04162 \tag{12}$$

It is interesting to note that this value for the critical level shows that the correct decision is to reject the null hypothesis at $\alpha=0.05$, while the use of Table A14 leads to the erroneous acceptance of $F^*(x)$ as the true distribution function at the same α level.

COMMENT. One of the most valuable features of the Kolmogorov two-sided test statistic is that its $1-\alpha$ quantile $w_{1-\alpha}$ may be used to form a confidence band for the true unknown distribution function. Recall that in finding a confidence interval for some unknown parameter, we first drew a random sample and then, from that sample, computed an upper value U and a lower value L that contained the unknown parameter between them with a certain probability $1-\alpha$, called the confidence coefficient. It would be convenient if we could do the same thing to obtain a "confidence band" within which the entire unknown distribution function would lie, with probability $1-\alpha$. Then we could draw a random sample for some population whose distribution function is completely unknown, and we could place some bounds on a graph and make the statement that the unknown distribution function lies entirely within those bounds, with some probability $1-\alpha$ that the statement is correct.

Confidence Band for the Population Distribution Function

DATA. The data consist of a random sample $X_1, X_2, \ldots, X_n$ of size n associated with some unknown distribution function, denoted by $F(x)$.

ASSUMPTIONS

1. The sample is a random sample.
2. For the confidence coefficient to be exact, the random variables should be continuous. If the random variables are discrete, the confidence band is conservative; that is, the true but unknown confidence coefficient is greater than the stated one.

METHOD. Draw a graph of the empirical distribution function $S(x)$ based on the random sample. To form a confidence band with a confidence coefficient $1-\alpha$, find the $1-\alpha$ quantile of the Kolmogorov test statistic from Table A14 for the two-sided test (if a two-sided confidence band is desired) and for the appropriate sample size n. Let $w_{1-\alpha}$ denote this quantile. Draw a graph above $S(x)$ a distance $w_{1-\alpha}$ and call this graph $U(x)$. Draw a second graph a distance $w_{1-\alpha}$ below $S(x)$ and call this second graph $L(x)$. Then $U(x)$ and $L(x)$ form the upper and lower boundaries, respectively, of a $1-\alpha$ confidence band that contains the unknown $F(x)$ completely within its boundaries.

There is no reason for $U(x)$ to be drawn above 1.0 even though $S(x)+w_{1-\alpha}$ might exceed 1.0, because we know that no distribution function ever exceeds 1.0. For the same reason $L(x)$ should not extend below the horizontal axis. The formal mathematical definitions of $U(x)$ and $L(x)$ are as follows.

$$\begin{aligned} U(x)&=S(x)+w_{1-\alpha} && \text{if} \quad S(x)+w_{1-\alpha}\leq 1\\ U(x)&=1.0 && \text{if} \quad S(x)+w_{1-\alpha}>1 \end{aligned} \tag{13}$$

$$\begin{aligned} L(x)&=S(x)-w_{1-\alpha} && \text{if} \quad S(x)-w_{1-\alpha}\geq 0\\ L(x)&=0 && \text{if} \quad S(x)-w_{1-\alpha}<0 \end{aligned} \tag{14}$$

The resulting probability statement is

$$P[L(x)\leq F(x)\leq U(x), \text{ for all } x]\geq 1-\alpha \tag{15}$$

where the last inequality applies only when the random variables are discrete.

REFERENCE ON K-S TEST
FOR COMPARING TWO DISTRIBUTIONS

this assumption, data were collected on eight streams and rivers of various sizes. The data consisted of stream flow (cubic feet per second) measurements taken once a week for various numbers of weeks. The logarithms of the data were tested for normality using the Shapiro–Wilk test, with the following results.

Stream Number	*Weeks of Record*	*Value of T_3*
1	8	.972
2	10	.858
3	6	.875
4	14	.840
5	9	.966
6	10	.924
7	14	.881
8	12	.868

Do the combined results indicate that stream flow data tend to follow a lognormal distribution?

8. The total yearly rainfall is sometimes assumed to follow a normal distribution. Ten cities across the United States were selected to test this assumption. Annual rainfall records were analyzed using the Shapiro–Wilk test, with the following results.

City	*Years of Record*	*Value of T_3*
1	18	.875
2	34	.874
3	26	.948
4	43	.980
5	40	.937
6	29	.915
7	35	.915
8	38	.890
9	42	.963
10	47	.941

Do the combined results indicate that annual rainfall follows a normal distribution?

6.3. TESTS ON TWO INDEPENDENT SAMPLES

The tests presented in this section are useful in situations where two samples are drawn, one from each of two possibly different populations, and the experimenter wishes to determine whether the two distribution functions associated with the two populations are identical or not. While other tests such as the median test, the Mann–Whitney test, or the parametric t test may also be appropriate, they are sensitive to differences between the two means or medians, but they may not detect differences of other types, such as differences in variances. One of the advantages of the two two-sided tests presented in this

section is that both tests are consistent against all types of differences that may exist between the two distribution functions.

The first test presented is the Smirnov test (Smirnov, 1939). It is a two-sample version of the Kolmogorov test presented in Section 6.1 and is sometimes called the Kolmogorov–Smirnov two-sample test, while the Kolmogorov test is sometimes called the Kolmogorov–Smirnov one-sample test. The Smirnov test is presented in the one-sided and two-sided versions. Another two-sided test, the Cramér–von Mises test for two samples, is also presented. It is slightly more difficult to compute than the Smirnov test, but it appeals to some people because it seems to make more effective use of the data. Actually, there is probably little difference in power between the two tests.

The Smirnov Test

DATA. The data consist of two independent random samples, one of size n, $X_1, X_2, \ldots, X_n$, and the other of size m, $Y_1, Y_2, \ldots, Y_m$. Let $F(x)$ and $G(x)$ represent their respective, unknown, distribution functions.

ASSUMPTIONS

1. The samples are random samples.
2. The two samples are mutually independent.
3. The measurement scale is at least ordinal.
4. For this test to be exact the random variables are assumed to be continuous.

If the random variables are discrete, the test is still valid but becomes conservative (Noether, 1967a).

HYPOTHESES

A. (Two-Sided Test)

$$H_0: F(x) = G(x) \quad \text{for all } x \text{ from } -\infty \text{ to } +\infty$$

$$H_1: F(x) \neq G(x) \quad \text{for at least one value of } x$$

B. (One-Sided Test)

$$H_0: F(x) \leq G(x) \quad \text{for all } x \text{ from } -\infty \text{ to } +\infty$$

$$H_1: F(x) > G(x) \quad \text{for at least one value of } x$$

This alternative hypothesis is sometimes stated as, "The Xs tend to be *smaller* than the Ys," which is a more general form of location alternatives than the statement that the Xs and Ys differ only by a location parameter (means or medians).

C. (One-Sided Test)

$$H_0: F(x) \geq G(x) \qquad \text{for all } x \text{ from } -\infty \text{ to } +\infty$$

$$H_1: F(x) < G(x) \qquad \text{for at least one value of } x$$

This is the one-sided test to use if it is suspected that the Xs might be shifted to the right (i.e., larger) of the Ys.

TEST STATISTIC. Let $S_1(x)$ be the empirical distribution function based on the random sample $X_1, X_2, \ldots, X_n$, and let $S_2(x)$ be the empirical distribution function based on the other random sample $Y_1, Y_2, \ldots, Y_m$. The test statistic is defined differently for the three different sets of hypotheses.

A. (Two-Sided Test) Define the test statistic T_1 as the greatest vertical distance between the two empirical distribution functions.

(1)
$$T_1 = \sup_x |S_1(x) - S_2(x)|$$

B. (One-Sided Test) Denote the test statistic by T_1^+ and let it equal the greatest vertical distance attained by $S_1(x)$ above $S_2(x)$.

(2)
$$T_1^+ = \sup_x [S_1(x) - S_2(x)]$$

C. (One-Sided Test) For the one-sided hypotheses in C above, let the test statistic, denoted by T_1^-, be the greatest vertical distance attained by $S_2(x)$ above $S_1(x)$.

(3)
$$T_1^- = \sup_x [S_2(x) - S_1(x)]$$

DECISION RULE. Reject H_0 at the level of significance α if the appropriate test statistic T_1, T_1^+, or T_1^-, as the case may be, exceeds its $1-\alpha$ quantile as given by Table A20 if $n = m$ and by Table A21 if $n \neq m$. For the one-sided tests those tables give the .90, .95, .975, .99, and .995 quantiles. For the two-sided test the .80, .90, .95, .98, and .99 quantiles are furnished. The large sample approximations given at the end of the tables may be used for the sample sizes not covered by the tables.

Example 1. A random sample of size 9, $X_1, \ldots, X_9$ is obtained from one population, and a random sample of size 15, $Y_1, \ldots, Y_{15}$ is obtained from a second population. The null hypothesis is that the two populations have identical distribution functions. If the respective distribution functions are denoted by $F(x)$ and $G(x)$, then the null hypothesis may be written as

$$H_0: F(x) = G(x) \qquad \text{for all } x \text{ from } -\infty \text{ to } +\infty$$

The alternative hypothesis may be stated as

$$H_1: F(x) \neq G(x) \qquad \text{for at least one value of } x$$

The two samples are ordered from smallest to largest for convenience, and

their values, along with other pertinent information about their empirical distribution functions, are given next.

X_i	Y_i	$S_1(x) - S_2(x)$	X_i	Y_i	$S_1(x) - S_2(x)$
	5.2	$0 - 1/15 = -1/15$		9.8	$5/9 - 8/15 = 1/45$
	5.7	$0 - 2/15 = -2/15$	9.9		$6/9 - 8/15 = 2/15$
	5.9	$0 - 3/15 = -1/5$	10.1		$7/9 - 8/15 = 11/45$
	6.5	$0 - 4/15 = -4/15$	10.6		$8/9 - 8/15 = 16/45$
	6.8	$0 - 5/15 = -1/3$		10.8	$8/9 - 9/15 = 13/45$
7.6		$1/9 - 5/15 = -2/9$	11.2		$1 - 9/15 = 2/5$
	8.2	$1/9 - 6/15 = -13/45$		11.3	$1 - 10/15 = 1/3$
8.4		$2/9 - 6/15 = -8/45$		11.5	$1 - 11/15 = 4/15$
8.6		$3/9 - 6/15 = -1/15$		12.3	$1 - 12/15 = 1/5$
8.7		$4/9 - 6/15 = 2/45$		12.5	$1 - 13/15 = 2/15$
	9.1	$4/9 - 7/15 = -1/45$		13.4	$1 - 14/15 = 1/15$
9.3		$5/9 - 7/15 = 4/45$		14.6	$1 - 1 = 0$

The test statistic for the two-sided test is given by Equation 1 as

$$T_1 = \sup_x |S_1(x) - S_2(x)|$$
$$= \tfrac{2}{5} = .400$$

the largest absolute difference between $S_1(x)$ and $S_2(x)$, which happens to occur between $x = 11.2$ and $x = 11.3$. The value of .400 for T_1 could also have been determined graphically by drawing graphs of $S_1(x)$ and $S_2(x)$ on the same coordinate axes. From the graphs one can easily see that the difference $S_1(x) - S_2(x)$ changes only at those observed values $x = X_i$ or $x = Y_j$, and that is why it is sufficient to compute $S_1(x) - S_2(x)$ only at the observed sample values, as done here.

From Table A21 we see that the .95 quantile of T_1, for the two-sided test and for $n = 9 = N_1$ and $m = 15 = N_2$, is given as $w_{.95} = 8/15$. For these data T_1 equals 2/5 or 6/15. Therefore H_0 is accepted at the .05 level. From the table, the critical level $\hat{\alpha}$ may be estimated as slightly larger than .20.

For the sake of comparison, the approximate .95 quantile based on the asymptotic distribution is found to be

$$w_{.95} \cong 1.36\sqrt{\frac{m+n}{mn}} = .573$$

which is slightly larger than the exact value of $8/15 = .533$. This illustrates the tendency of the asymptotic approximation to furnish a conservative test.

Note that many of the calculations performed in this example could have been eliminated because, either by an inspection of the data or a preliminary sketch of $S_1(x)$ and $S_2(x)$, many of the values of X_i and Y_j may be seen to be unlikely candidates for yielding the maximum value of $|S_1(x) - S_2(x)|$ and therefore may be ignored in favor of the more likely values of X_i and Y_j.

If a one-sided test had been appropriate instead of the two-sided test, the statistics

$$T_1^+ = \sup_x [S_1(x) - S_2(x)] = \tfrac{2}{5} = .400$$

for the set B of hypotheses, and

$$T_1^- = \sup_x [S_2(x) - S_1(x)] = \tfrac{1}{3} = .333$$

for the set C of hypotheses are easily determined from the preceding table of data. The critical levels for both of the one sided tests are seen from Table A21 to be greater than .10.

□ *Theory.* Although it may not be apparent at first, the statistics T_1, T_1^+, and T_1^- depend only on the order of the Xs and Ys in the ordered combined sample of Xs and Ys and do not require actual knowledge of the numerical values of the observations. To illustrate this, suppose there are 3Xs and 2Ys. There are $\binom{5}{2} = 10$ different ordered arrangements of the combined sample. These arrangements are given next, along with the values of T_1, T_1^+, and T_1^- for each ordered arrangement.

Arrangement	T_1	T_1^+	T_1^-	*Arrangement*	T_1	T_1^+	T_1^-
$X<X<X<Y<Y$	1	1	0	$X<Y<X<Y<X$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
$X<X<Y<X<Y$	$\frac{2}{3}$	$\frac{2}{3}$	0	$Y<X<X<Y<X$	$\frac{1}{2}$	$\frac{1}{6}$	$\frac{1}{2}$
$X<Y<X<X<Y$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{6}$	$X<Y<Y<X<X$	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{2}{3}$
$Y<X<X<X<Y$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$Y<X<Y<X<X$	$\frac{2}{3}$	0	$\frac{2}{3}$
$X<X<Y<Y<X$	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{1}{3}$	$Y<Y<X<X<X$	1	0	1

If the null hypothesis in the two-sided test is true, the two distribution functions are equal and each ordered arrangement is equally likely under the assumption of continuous random variables. This same point was discussed more thoroughly in connection with the Mann–Whitney test in Section 5.1. Therefore, in the two-sided test, the probability associated with each ordered arrangement is given by

$$\text{probability} = \frac{1}{\binom{m+n}{n}} = \frac{1}{\binom{5}{3}} = \frac{1}{10} \tag{4}$$

and from this the following probability distributions can be deduced.

$P(T_1 = \frac{1}{3}) = \frac{1}{10}$	$P(T_1^+ = 0) = \frac{1}{5}$	$P(T_1^- = 0) = \frac{1}{5}$
$P(T_1 = \frac{1}{2}) = \frac{3}{10}$	$P(T_1^+ = \frac{1}{6}) = \frac{1}{10}$	$P(T_1^- = \frac{1}{6}) = \frac{1}{10}$
$P(T_1 = \frac{2}{3}) = \frac{2}{5}$	$P(T_1^+ = \frac{1}{3}) = \frac{1}{5}$	$P(T_1^- = \frac{1}{3}) = \frac{1}{5}$
$P(T_1 = 1) = \frac{1}{5}$	$P(T_1^+ = \frac{1}{2}) = \frac{1}{5}$	$P(T_1^- = \frac{1}{2}) = \frac{1}{5}$
	$P(T_1^+ = \frac{2}{3}) = \frac{1}{5}$	$P(T_1^- = \frac{2}{3}) = \frac{1}{5}$
	$P(T_1^+ = 1) = \frac{1}{10}$	$P(T_1^- = 1) = \frac{1}{10}$

It is no coincidence that the distributions of T_1^+ and T_1^- are identical with each other for $n=3$ and $m=2$. They are identical with each other for all choices of n and m. However, the space-saving technique used in Tables A20 and A21 of stating that the $1-\alpha$ quantile of T_1 in the two-sided test equals the $1-\alpha/2$ quantile of T_1^+ in the one-sided test is a valid technique only if α is small. Notice, for example, in the preceding illustration that $P(T_1 \geq 1)$ equals twice $P(T_1^+ \geq 1)$, and $P(T_1 \geq 2/3)$ equals twice $P(T_1^+ \geq 2/3)$, but $P(T_1 \geq 1/2)$ does not equal twice $P(T_1^+ \geq 1/2)$.

The null distribution (i.e., the distribution when H_0 is true) in the one-sided tests is also found in the manner just described because, under the one-sided null hypotheses, the size of the critical region is a maximum when $F(x)$ is identical with $G(x)$. If the two samples are of equal size, it is not necessary to use this method to find the upper quantiles, because the distribution functions for T_1, T_1^+, and T_1^- were derived as a function of the sample size n by Gnedenko and Korolyuk (1951). The derivation of these distribution functions is interesting, and it is within the presumed mathematical grasp of the reader, but its length precludes its presentation here. The reader is referred to Fisz (1963) for a readable presentation of the derivation.

For samples of unequal size the method of finding quantiles is essentially as illustrated. However, many refinements using path-counting methods have simplified the bookkeeping enough so that extensive tables exist (Harter and Owen, 1970). See Steck (1969) for a general discussion of the Smirnov test. Kim (1969) gives some closer approximations to the exact quantiles when exact tables are not available.

A modification of the Smirnov test was suggested by Tsao (1954) so that the test may be applied to truncated samples. That is, perhaps only the Xs and Ys less than $X^{(r)}$ are observed, as sometimes happens in life-testing experiments. The Smirnov test may then be applied to the truncated samples with the aid of tables derived recursively by Tsao (1954). The distribution functions of Tsao's statistics were derived analytically by Conover (1967a). Extensions of the Smirnov test to three or more samples are presented in the next section.

The next test is the Cramér–von Mises goodness-of-fit test. This test is two-sided only and involves slightly more calculations than the Smirnov test does.

The Cramér–von Mises Two-Sample Test

DATA. The data consist of two independent random samples, $X_1, \ldots, X_n$ and $Y_1, \ldots, Y_m$, with unknown distribution functions $F(x)$ and $G(x)$, respectively.

ASSUMPTIONS

1. The samples are random samples, independent of each other.
2. The measurement scale is at least ordinal.

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ON THE KOLMOGOROV-SMIRNOV TEST FOR NORMALITY WITH MEAN AND VARIANCE UNKNOWN

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The standard tables used for the Kolmogorov-Smirnov test are valid when testing whether a set of observations are from a completely specified continuous distribution. If one or more parameters must be estimated from the sample then the tables are no longer valid.

A table is given in this note for use with the Kolmogorov-Smirnov statistic for testing whether a set of observations is from a normal population when the mean and variance are not specified but must be estimated from the sample. The table is obtained from a Monte Carlo calculation.

A brief Monte Carlo investigation is made of the power of the test.

THE Kolmogorov-Smirnov statistic provides a means of testing whether a set of observations are from some completely specified continuous distribution, $F_0(X)$. The usual alternative would be the chi-square test. The Kolmogorov-Smirnov test has at least two major advantages over the chi-square test [ref. 1, 2].

1. It can be used with small sample sizes, where the validity of the chi-square test would be questionable.
2. Often it appears to be a more powerful test than the chi-square test for any sample size.

Unfortunately, when certain parameters of the distribution must be estimated from the sample, then the Kolmogorov-Smirnov test no longer applies—at least not using the commonly tabulated critical points. It is suggested in ref. 2 that if the test is used in this case, the results will be conservative in the sense that the probability of a type I error will be smaller than as given by tables of the Kolmogorov-Smirnov statistic [as found in ref. 2 or 4]. As will be seen below, the results of this procedure will indeed be extremely conservative.

In ref. 1 it is pointed out that if the parameters to be estimated are parameters of scale or location, then one can construct tables for use with the Kolmogorov-Smirnov statistic for that particular distribution.

This note presents a table for use with the Kolmogorov-Smirnov statistic when testing that a set of observations are from a normal population but the mean and variance are not specified.

The procedure is: Given a sample of N observations, one determines $D = \max_X | F^*(X) - S_N(X) |$, where $S_N(X)$ is the sample cumulative distribution function and $F^*(x)$ is the cumulative normal distribution function with $\mu = \bar{X}$, the sample mean, and $\sigma^2 = s^2$, the sample variance, defined with denominator $n-1$. If the value of D exceeds the critical value in the table, one rejects the hypothesis that the observations are from a normal population.

The values in the table were obtained by a Monte Carlo calculation. For each value of N, 1,000 or more samples were drawn and the distribution of D was thus estimated. The calculations were performed at The George Washington University Computing Center.

When the values are compared with those in the standard table for the Kolmogorov-Smirnov test [ref. 2, 4] it is found that the Monte Carlo critical values are in most cases approximately two-thirds the standard values. Since the ratio of the Monte Carlo values to the standard values remains relatively fixed, especially for the larger values of N, it appeared that the values were then decreasing as $1/\sqrt{N}$. The Monte Carlo values for a sample of size 40 were multiplied by the square root of 40 and the result was used as the numerator for the critical values for sample sizes greater than 30. In ref. 3 values were obtained via a similar calculation for $N=100$ using 400 samples. The values were in accord with the "asymptotic" values given in Table 1.

Comparing Table 1 with the standard table for the Kolmogorov-Smirnov test from ref. 2, it is seen that the critical values in Table 1 for a .01 significance level are for each value of N slightly smaller than critical values for a .20 significance level using the standard tables. Thus the result of using the standard table when values of the mean and standard deviation are estimated from the

TABLE 1. TABLE OF CRITICAL VALUES OF D

The values of D given in the table are critical values associated with selected values of N. Any value of D which is greater than or equal to the tabulated value is significant at the indicated level of significance. These values were obtained as a result of Monte Carlo calculations, using 1,000 or more samples for each value of N.

Sample Size N	Level of Significance for $D=\text{Max}\mid F^*(X)-S_N(X)\mid$				
	.20	.15	.10	.05	.01
4	.300	.319	.352	.381	.417
5	.285	.299	.315	.337	.405
6	.265	.277	.294	.319	.364
7	.247	.258	.276	.300	.348
8	.233	.244	.261	.285	.331
9	.223	.233	.249	.271	.311
10	.215	.224	.239	.258	.294
11	.206	.217	.230	.249	.284
12	.199	.212	.223	.242	.275
13	.190	.202	.214	.234	.268
14	.183	.194	.207	.227	.261
15	.177	.187	.201	.220	.257
16	.173	.182	.195	.213	.250
17	.169	.177	.189	.206	.245
18	.166	.173	.184	.200	.239
19	.163	.169	.179	.195	.235
20	.160	.166	.174	.190	.231
25	~~.149~~ .142(1)	~~.153~~ .147	~~.165~~ .158	~~.189~~ .173	~~.203~~ .200
30	.131	.136	.144	.161	.187
Over 30	$\frac{.736}{\sqrt{N}}$	$\frac{.768}{\sqrt{N}}$	$\frac{.805}{\sqrt{N}}$	$\frac{.886}{\sqrt{N}}$	$\frac{1.031}{\sqrt{N}}$

(1) Corrected values from Lilliefors (1969) Journal of American Statistical ~~Society~~ Association 64 p1702

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VALUES OF D

s associated with selected values
the tabulated value is significant
re obtained as a result of Monte
value of N.

Max $\|F^*(X)-S_N(X)\|$	
.05	.01
.381	.417
.337	.405
.319	.364
.300	.348
.285	.331
.271	.311
.258	.294
.249	.284
.242	.275
.234	.268
.227	.261
.220	.257
.213	.250
.206	.245
.200	.239
.195	.235
.190	.231
.180	.203
.161	.187
$\frac{.886}{\sqrt{N}}$	$\frac{1.031}{\sqrt{N}}$

TABLE 2

Probability of rejecting hypothesis of normality using D statistic and chi-square statistic when sample size is 20. The numbers are the result of Monte Carlo calculations with 500 samples for each distribution.

Underlying Distribution	Kolmogorov-Smirnov test		Chi-Square test	
	Using Critical Values From Table 1		Using Monte Carlo Critical Values	
	$\alpha=.05$	$\alpha=.10$	$\alpha=.06$	$\alpha=.12$
Normal	.06	.10	.06	.12
Chi-square, 3 d.f.	.44	.55	.20	.27
Student's t, 3 d.f.	.50	.58	.40	.52
Exponential	.61	.72	.29	.41
Uniform	.12	.22	.10	.18

sample would be to obtain an extremely conservative test in the sense that the actual significance level would be much lower than that given by the table.

It would appear that this specialized Kolmogorov-Smirnov test for normality should have the same advantages over the chi-square test as does the usual Kolmogorov-Smirnov test when testing for a completely specified distribution. Clearly it provides a test which can be used with sample sizes which are too small for use of the chi-square test. It is shown in ref. 3 that asymptotically it is more powerful than the chi-square test.

A brief Monte Carlo investigation was made of the power of this test. Five hundred samples of size 20 were drawn from each of several distributions. The probability of rejection using the Kolmogorov-Smirnov test (Table 1) was determined. The results are given in Table 2. The value of chi-square was also determined for each sample (using four intervals). The intervals were determined so as to have equal probabilities under the fitted normal curve. It was shown in ref. 5 that the asymptotic distribution of chi-square lies between chi-square with one degree of freedom and chi-square with three degrees of freedom. This is due to the use of maximum likelihood estimators based on the individual observations rather than data grouped into cell frequencies (in which case the distribution would be chi-square with one degree of freedom). When

TABLE 3

Probability of rejecting hypothesis of normality using D statistic when sample size is 10. The numbers are the result of Monte Carlo calculations with 500 samples for each distribution.

Underlying Distribution	$\alpha=.05$	$\alpha=.10$
Normal	.05	.10
Chi-Square, 3 d.f.	.23	.35
Student's t, 3 d.f.	.28	.36
Exponential	.34	.46
Uniform	.07	.13

the standard chi-square point for $\alpha = .05$ and one degree of freedom was compared to the Monte Carlo results it was found that the probability of a type I error was .11. Since this probability was so far from the nominal value, rejection points were determined for chi-square from the Monte Carlo calculations. The values of 5.2 and 4.0 were found to give probabilities of type I error of .06 and .12 respectively. The probability of rejection was tabulated using these new critical values.

Probabilities of rejecting the hypothesis of normality were also determined (again using a Monte Carlo calculation) for a sample of size 10 using the Kolmogorov-Smirnov statistic and the critical points of Table 1. These results are given in Table 3.

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[3] Kac, M., Kiefer, J., and Wolfowitz, J., "On Tests of Normality and Other Tests of Goodness of Fit Based on Distance Methods," *The Annals of Mathematical Statistics*, 26 (1955), 189–211.

[4] Birnbaum, Z. W., "Numerical Tabulation of the Distribution of Kolmogorov's Statistic for Finite Sample Size," *Journal of the American Statistical Association*, 47 (1952), 425–41.

[5] Chernoff, H. and Lehmann, E. L., "The Use of Maximum Likelihood Estimates in χ^2 Tests for Goodness of Fit," *The Annals of Mathematical Statistics*, 25 (1954), 579–86.

Consider the smallest n such that $H_n(i)>0$ for some $i\in M$. Then, $H_{n-1}(m)\le 0$ for all $m\in M$, and, hence, $H_n(i)\le H_n(j)$ when iTj. Therefore, there is a T-maximal element i of M such that $H_n(i)>0$. By

$$0 < H_n(i) \le H_{n+1}(i) \le \cdots \le \lambda_M(i) - r_M(i)\rho_M,$$

(4.3) must be violated at i. By i being T-maximal in M, $M' = M - \{i\} \in \Omega(\mathrm{T})$, completing the proof.

Krishnan, Marakatha, SERIES REPRESENTATIONS OF THE DOUBLY NONCENTRAL t-DISTRIBUTION, Vol. 63, No. 323 (September 1968), 1004–1012.

The author has written that on p. 1010, in line 3, t_1^2 should be replaced by t'^2 and in the first line of Section 5, the final 0 should be replaced by 0(1); also, in the references, Marakathavalli [8] is misspelled.

Lilliefors, Hubert W., ON THE KOLMOGOROV-SMIRNOV TEST FOR NORMALITY WITH MEAN AND VARIANCE UNKNOWN, Vol. 62, No. 318 (June 1967), 399–402.

The author is grateful to Carl B. Bates for pointing out that the values of Table 1 do not relate smoothly to the standard values at $N=25$. The values given for $N=25$ are wrong and should be replaced by .142, .147, .158, .173, and .200 respectively.

NOTES ABOUT AUTHORS, Vol. 64, No. 325 (March 1969), 406.

W. Y. TAN's title was given incorrectly. His correct title was Assistant Professor of Statistics.

Patil, Ganapati P. and Bildikar, Sheela, MULTIVARIATE LOGARITHMIC SERIES DISTRIBUTION AS A PROBABILITY MODEL IN POPULATION AND COMMUNITY ECOLOGY AND SOME OF ITS STATISTICAL PROPERTIES, Vol. 62, No. 318 (June 1967), 655–674.

Michael L. Goodman has kindly supplied the following corrections. In Table 2 (p. 667) the (2, 2), (2, 4), and (14, 26+) entries should be 0, 1, and 1 respectively. The corresponding marginal totals should be corrected, and the grand total should be 116.

In Table 3 (p. 668), the cells with expected frequencies 3.03, 4.60, and 3.36 should have observed frequencies 1, 3, and 4 respectively, and the observed χ^2 should be 74.92.

In Table 4 (p. 669), the cells with expected frequencies 3.16, 5.00, 3.44, and 6.18 should have observed frequencies 2, 6, 3, and 7 respectively, and the observed χ^2 should be 34.25.

In Table 5 (p. 670), the cells with expected frequencies 3.55, 3.15, and 4.61 should have observed frequencies 3, 3, and 6 respectively, the class 15+ for x_1 should be 16+, the degrees of freedom should be $19-3=16$, and the observed χ^2 should be 30.01.

Steffens, F. E., CRITICAL VALUES FOR BIVARIATE STUDENT t-TESTS, Vol. 64, No. 326 (June 1969), 637–646.

The following references should be added. The author is indebted to Dr.

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COHEN'S MAXIMUM LIKELIHOOD ESTIMATE FOR CENSORED SAMPLES

Dale Rezabek

Vol. 3, No. 4 TECHNOMETRICS November, 1961

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Tables for Maximum Likelihood Estimates: Singly Truncated and Singly Censored Samples*

A. Clifford Cohen, Jr.
The University of Georgia

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MAR 1989

In a previous paper in Technometrics, Vol. 1, 1959, the author derived the maximum liklihood estimates of the mean and variance for simply truncated or simply censored samples drawn from a Normal distribution. This paper extends considerably the tables originally published, and contains a further worked example.

Maximum likelihood estimators presented in the August 1959 issue of this journal [1] for the mean and variance of a normal distribution when samples are singly truncated or singly censored, involved only one auxiliary estimating function with each of these sample types. Estimates as well as their asymptotic variances are relatively easy to calculate when the necessary tables are available, but unfortunately the tables originally provided failed to prove adequate in all cases. The present paper constitutes a response to numerous requests for a more complete tabulation of the pertinent functions.

Our concern is with singly truncated samples and with singly censored samples of both types I and II when the random variable is normal (μ, σ). For all samples under consideration, N designates the total number of sample specimens, and n the number whose measurements are known. These three sample types are more completely described as follows:

Singly Truncated Samples. In samples of this type, a terminus x_0 is specified. Observation is possible only if $x \geq x_0$, in which case truncation is said to be *on the left*, or if $x \leq x_0$, in which case truncation is said to be *on the right*. In this case, measurements are known for all sample specimens and hence $N = n$. In certain applications it might be preferable to consider that the restriction (i.e. truncation) is imposed on the distribution rather then on the sample being observed. The adoption of this latter point of view involves no change in the estimators.

Type I Singly Censored Samples. As in the singly truncated samples, a terminus x_0 is specified, but in this case sample specimens whose measurements fall in the restricted interval of the random variable may be identified and thus counted, though not otherwise measured. When the restricted (censored) interval consists of all values $x < x_0$, censoring is said to occur *on the left*. When the censored interval consists of all values $x > x_0$, censoring is said to be *on the right*. The remaining specimens for which $x \geq x_0$ or $(x \leq x_0)$ are fully measured without restriction. Samples of this type thus consist of N observations of which n are fully measured and $N - n$ are censored with N being fixed and n a random variable.

* Sponsored by the Office of Ordnance Research, U. S. Army.

Type II Singly Censored Samples. In samples of this type, full measurement is made only for the n largest observations in which case censoring is *on the left* or for the n smallest observations in which case censoring is *on the right*. Of the remaining $N - n$ censored observations, it is known only that $x < x_n$ or $(x > x_n)$, where x_n is the smallest (or largest) fully measured observation. In samples of this type both N and n are fixed, but x_n is a random variable.

For the convenience of readers who might not have a copy of reference [1] available, the estimators obtained there are repeated below without derivation. The caret ($\hat{\ }$) serves to distinguish maximum likelihood estimators or estimates from the parameters being estimated.

Estimators for Singly Truncated Samples

$$\hat{\mu} = \bar{x} - \hat{\theta}(\bar{x} - x_0),$$
$$\hat{\sigma}^2 = s^2 + \hat{\theta}(\bar{x} - x_0)^2. \tag{1}$$

Estimators for Type I Singly Censored Samples

$$\hat{\mu} = \bar{x} - \hat{\lambda}(\bar{x} - x_0),$$
$$\hat{\sigma}^2 = s^2 + \hat{\lambda}(\bar{x} - x_0)^2. \tag{2}$$

Estimators for Type II Singly Censored Samples

$$\hat{\mu} = \bar{x} - \hat{\lambda}(\bar{x} - x_n),$$
$$\hat{\sigma}^2 = s^2 + \hat{\lambda}(\bar{x} - x_n)^2. \tag{3}$$

In case of the above cases, $\bar{x}$ and s^2 are the mean and variance respectively of the n measured sample observations.

$$\bar{x} = \sum_1^n x_i/n,$$
$$s^2 = \sum_1^n (x_i - \bar{x})^2/n. \tag{4}$$

The auxiliary estimating functions θ and λ were defined in [1] in connection with derivations of the above estimators. They are presented here in tables 1 and 2 as functions of γ and of γ and h respectively where $\gamma = [1-Z(Z-\xi)]/(Z-\xi)^2$ in the case of truncated samples, and $\gamma = [1 - Y(Y - \xi)]/(Y - \xi)^2$ in the case of censored samples. As defined in [1]

$$Z = \varphi(\xi)/[1 - F(\xi)], \quad \text{and} \quad Y = [h/(1 - h)]\varphi(\xi)/F(\xi),$$

where $F(\xi) = \int_{-\infty}^{\xi} \varphi(t)\,dt$, $\varphi(t) = (\sqrt{2}\pi)^{-1} \exp - t^2/2$, and where $\xi = (x_0 - \mu)/\sigma$ in truncated and type I censored samples, while $\xi = (x_n - \mu)/\sigma$ in type II censored samples. In both type I and type II censored samples, h is the proportion of censored observations; i.e. $h = (N - n)/N$.

In Table 1, which applies to truncated samples, $\theta(\gamma)$ is given at equal intervals of 0.001 for the argument γ, whereas in the original table, these intervals were unequal and somewhat wider. For any given truncated sample, after computing $\hat{\gamma} = s^2/(\bar{x} - x_0)^2$, enter table 1 with $\gamma = \hat{\gamma}$ and interpolate as necessary to obtain $\hat{\theta} = \theta(\hat{\gamma})$. Ordinarily, linear interpolation will be adequate. With $\hat{\theta}$ thus determined, the required estimates follow from (1).

Table 1. AUXILIARY ESTIMATION FUNCTION θ

For Singly Truncated Samples

γ	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009	γ
0.05	.00000	.00000	.00000	.00001	.00001	.00001	.00001	.00001	.00002	.00002	0.05
0.06	.00002	.00003	.00003	.00003	.00004	.00004	.00005	.00006	.00007	.00007	0.06
0.07	.00008	.00009	.00010	.00011	.00013	.00014	.00016	.00017	.00019	.00020	0.07
0.08	.00022	.00024	.00026	.00028	.00031	.00033	.00036	.00039	.00042	.00045	0.08
0.09	.00048	.00051	.00055	.00059	.00063	.00067	.00071	.00075	.00080	.00085	0.09
0.10	.00090	.00095	.00101	.00106	.00112	.00118	.00125	.00131	.00138	.00145	0.10
0.11	.00153	.00160	.00168	.00176	.00184	.00193	.00202	.00211	.00220	.00230	0.11
0.12	.00240	.00250	.00261	.00272	.00283	.00294	.00305	.00317	.00330	.00342	0.12
0.13	.00355	.00369	.00382	.00396	.00410	.00425	.00440	.00455	.00470	.00486	0.13
0.14	.00503	.00519	.00536	.00553	.00571	.00589	.00608	.00627	.00646	.00665	0.14
0.15	.00685	.00705	.00726	.00747	.00769	.00791	.00813	.00835	.00858	.00882	0.15
0.16	.00906	.00930	.00955	.00980	.01006	.01032	.01058	.01085	.01112	.01140	0.16
0.17	.01168	.01197	.01226	.01256	.01286	.01316	.01347	.01378	.01410	.01443	0.17
0.18	.01476	.01509	.01543	.01577	.01611	.01646	.01682	.01718	.01755	.01792	0.18
0.19	.01830	.01868	.01907	.01946	.01986	.02026	.02067	.02108	.02150	.02193	0.19
0.20	.02236	.02279	.02323	.02368	.02413	.02458	.02504	.02551	.02599	.02647	0.20
0.21	.02695	.02744	.02794	.02844	.02895	.02946	.02998	.03050	.03103	.03157	0.21
0.22	.03211	.03266	.03322	.03378	.03435	.03492	.03550	.03609	.03668	.03728	0.22
0.23	.03788	.03849	.03911	.03973	.04036	.04100	.04165	.04230	.04296	.04362	0.23
0.24	.04429	.04497	.04565	.04634	.04704	.04774	.04845	.04917	.04989	.05062	0.24
0.25	.05136	.05211	.05286	.05362	.05439	.05516	.05594	.05673	.05753	.05834	0.25
0.26	.05915	.05997	.06080	.06163	.06247	.06332	.06418	.06504	.06591	.06679	0.26
0.27	.06768	.06858	.06948	.07039	.07131	.07224	.07317	.07412	.07507	.07603	0.27
0.28	.07700	.07797	.07896	.07995	.08095	.08196	.08298	.08401	.08504	.08609	0.28
0.29	.08714	.08820	.08927	.09035	.09144	.09254	.09364	.09476	.09588	.09701	0.29
0.30	.09815	.09930	.10046	.10163	.10281	.10400	.10520	.10641	.10762	.10885	0.30
0.31	.1101	.1113	.1126	.1138	.1151	.1164	.1177	.1190	.1203	.1216	0.31
0.32	.1230	.1243	.1257	.1270	.1284	.1298	.1312	.1326	.1340	.1355	0.32
0.33	.1369	.1383	.1398	.1413	.1428	.1443	.1458	.1473	.1488	.1503	0.33
0.34	.1519	.1534	.1550	.1566	.1582	.1598	.1614	.1630	.1647	.1663	0.34
0.35	.1680	.1697	.1714	.1731	.1748	.1765	.1782	.1800	.1817	.1835	0.35
0.36	.1853	.1871	.1889	.1907	.1926	.1944	.1963	.1982	.2001	.2020	0.36
0.37	.2039	.2058	.2077	.2097	.2117	.2136	.2156	.2176	.2197	.2217	0.37
0.38	.2238	.2258	.2279	.2300	.2321	.2342	.2364	.2385	.2407	.2429	0.38
0.39	.2451	.2473	.2495	.2517	.2540	.2562	.2585	.2608	.2631	.2655	0.39
0.40	.2678	.2702	.2726	.2750	.2774	.2798	.2822	.2847	.2871	.2896	0.40
0.41	.2921	.2947	.2972	.2998	.3023	.3049	.3075	.3102	.3128	.3155	0.41
0.42	.3181	.3208	.3235	.3263	.3290	.3318	.3346	.3374	.3402	.3430	0.42
0.43	.3459	.3487	.3516	.3545	.3575	.3604	.3634	.3664	.3694	.3724	0.43
0.44	.3755	.3785	.3816	.3847	.3878	.3910	.3941	.3973	.4005	.4038	0.44
0.45	.4070	.4103	.4136	.4169	.4202	.4236	.4269	.4303	.4338	.4372	0.45
0.46	.4407	.4442	.4477	.4512	.4547	.4583	.4619	.4655	.4692	.4728	0.46
0.47	.4765	.4802	.4840	.4877	.4915	.4953	.4992	.5030	.5069	.5108	0.47
0.48	.5148	.5187	.5227	.5267	.5307	.5348	.5389	.5430	.5471	.5513	0.48
0.49	.5555	.5597	.5639	.5682	.5725	.5768	.5812	.5856	.5900	.5944	0.49
0.50	.5989	.6034	.6079	.6124	.6170	.6216	.6263	.6309	.6356	.6404	0.50
0.51	.6451	.6499	.6547	.6596	.6645	.6694	.6743	.6793	.6843	.6893	0.51
0.52	.6944	.6995	.7046	.7098	.7150	.7202	.7255	.7308	.7361	.7415	0.52
0.53	.7469	.7524	.7578	.7633	.7689	.7745	.7801	.7857	.7914	.7972	0.53
0.54	.8029	.8087	.8146	.8204	.8263	.8323	.8383	.8443	.8504	.8565	0.54
0.55	.8627	.8689	.8751	.8813	.8876	.8940	.9004	.9068	.9133	.9198	0.55
0.56	.9264	.9330	.9396	.9463	.9530	.9598	.9666	.9735	.9804	.9874	0.56
0.57	.9944	1.001	1.009	1.016	1.023	1.030	1.037	1.045	1.052	1.060	0.57
0.58	1.067	1.075	1.082	1.090	1.097	1.105	1.113	1.121	1.129	1.137	0.58
0.59	1.145	1.153	1.161	1.169	1.177	1.185	1.194	1.202	1.211	1.219	0.59
0.60	1.228	1.236	1.245	1.254	1.262	1.271	1.280	1.289	1.298	1.307	0.60
0.61	1.316	1.326	1.335	1.344	1.353	1.363	1.373	1.382	1.392	1.402	0.61
0.62	1.411	1.421	1.431	1.441	1.451	1.461	1.472	1.482	1.492	1.503	0.62
0.63	1.513	1.524	1.534	1.545	1.556	1.567	1.578	1.589	1.600	1.611	0.63
0.64	1.622	1.634	1.645	1.657	1.668	1.680	1.692	1.704	1.716	1.728	0.64
0.65	1.740	1.752	1.764	1.777	1.789	1.802	1.814	1.827	1.840	1.853	0.65
0.66	1.866	1.879	1.892	1.905	1.919	1.932	1.946	1.960	1.974	1.988	0.66
0.67	2.002	2.016	2.030	2.044	2.059	2.073	2.088	2.103	2.118	2.133	0.67
0.68	2.148	2.163	2.179	2.194	2.210	2.225	2.241	2.257	2.273	2.290	0.68
0.69	2.306	2.322	2.339	2.356	2.373	2.390	2.407	2.424	2.441	2.459	0.69
0.70	2.477	2.495	2.512	2.531	2.549	2.567	2.586	2.605	2.623	2.643	0.70
0.71	2.662	2.681	2.701	2.720	2.740	2.760	2.780	2.800	2.821	2.842	0.71
0.72	2.863	2.884	2.905	2.926	2.948	2.969	2.991	3.013	3.036	3.058	0.72
0.73	3.081	3.104	3.127	3.150	3.173	3.197	3.221	3.245	3.270	3.294	0.73
0.74	3.319	3.344	3.369	3.394	3.420	3.446	3.472	3.498	3.525	3.552	0.74
0.75	3.579	3.606	3.634	3.662	3.690	3.718	3.747	3.776	3.805	3.834	0.75
0.76	3.864	3.894	3.924	3.955	3.986	4.017	4.048	4.080	4.112	4.144	0.76
0.77	4.177	4.210	4.243	4.277	4.311	4.345	4.380	4.415	4.450	4.486	0.77
0.78	4.52	4.56	4.60	4.63	4.67	4.71	4.75	4.79	4.82	4.86	0.78
0.79	4.90	4.94	4.99	5.03	5.07	5.11	5.15	5.20	5.24	5.28	0.79
0.80	5.33	5.37	5.42	5.46	5.51	5.56	5.61	5.65	5.70	5.75	0.80
0.81	5.80	5.85	5.90	5.95	6.01	6.06	6.11	6.17	6.22	6.28	0.81
0.82	6.33	6.39	6.45	6.50	6.56	6.62	6.68	6.74	6.81	6.87	0.82
0.83	6.93	7.00	7.06	7.13	7.19	7.26	7.33	7.40	7.47	7.54	0.83
0.84	7.61	7.68	7.76	7.83	7.91	7.98	8.06	8.14	8.22	8.30	0.84
0.85	8.39	8.47	8.55	8.64	8.73	8.82	8.91	9.00	9.09	9.18	0.85

Table 2. AUXILIARY ESTIMATION FUNCTION $\lambda(h,\gamma)$
For Singly Censored Samples

γ \ h	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.15	.20	h / γ
.00	.010100	.020400	.030902	.041583	.052507	.063827	.074953	.086488	.09824	.11020	.17342	.24268	.00
.05	.010551	.021294	.032225	.043350	.054670	.066189	.077909	.089834	.10197	.11431	.17935	.25033	.05
.10	.010950	.022082	.033398	.044902	.056596	.068483	.080568	.092852	.10534	.11804	.18479	.25741	.10
.15	.011310	.022798	.034466	.046318	.058356	.070586	.083009	.095629	.10845	.12148	.18985	.26405	.15
.20	.011642	.023459	.035453	.047629	.059990	.072539	.085280	.098216	.11135	.12469	.19460	.27031	.20
.25	.011952	.024076	.036377	.048858	.061522	.074372	.087413	.10065	.11408	.12772	.19910	.27626	.25
.30	.012243	.024658	.037249	.050018	.062969	.076106	.089433	.10295	.11667	.13059	.20338	.28193	.30
.35	.012520	.025211	.038077	.051120	.064345	.077758	.091355	.10515	.11914	.13333	.20747	.28737	.35
.40	.012784	.025738	.038866	.052173	.065660	.079332	.093193	.10725	.12150	.13595	.21139	.29260	.40
.45	.013036	.026243	.039624	.053182	.066921	.080845	.094958	.10926	.12377	.13847	.21517	.29765	.45
.50	.013279	.026728	.040352	.054153	.068135	.082301	.096657	.11121	.12595	.14090	.21882	.30253	.50
.55	.013513	.027196	.041054	.055089	.069306	.083708	.098298	.11308	.12806	.14325	.22235	.30725	.55
.60	.013739	.027649	.041733	.055995	.070439	.085068	.099887	.11490	.13011	.14552	.22578	.31184	.60
.65	.013958	.028087	.042391	.056874	.071538	.086388	.10143	.11666	.13209	.14773	.22910	.31630	.65
.70	.014171	.028513	.043030	.057726	.072605	.087670	.10292	.11837	.13402	.14987	.23234	.32065	.70
.75	.014378	.028927	.043652	.058556	.073643	.088917	.10438	.12004	.13590	.15196	.23550	.32489	.75
.80	.014579	.029330	.044258	.059364	.074655	.090133	.10580	.12167	.13773	.15400	.23858	.32903	.80
.85	.014775	.029723	.044848	.060153	.075642	.091319	.10719	.12325	.13952	.15599	.24158	.33307	.85
.90	.014967	.030107	.045425	.060923	.076606	.092477	.10854	.12480	.14126	.15793	.24452	.33703	.90
.95	.015154	.030483	.045989	.061676	.077549	.093611	.10987	.12632	.14297	.15983	.24740	.34091	.95
1.00	.015338	.030850	.046540	.062413	.078471	.094720	.11118	.12780	.14465	.16170	.25022	.34471	1.00

γ \ h	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.80	.90	h / γ
.00	.31862	.4021	.4941	.5961	.7096	.8368	.9808	1.145	1.336	1.561	2.176	3.283	.00
.05	.32793	.4130	.5066	.6101	.7252	.8540	.9994	1.166	1.358	1.585	2.203	3.314	.05
.10	.33662	.4233	.5184	.6234	.7400	.8703	1.017	1.185	1.379	1.608	2.229	3.345	.10
.15	.34480	.4330	.5296	.6361	.7542	.8860	1.035	1.204	1.400	1.630	2.255	3.376	.15
.20	.35255	.4422	.5403	.6483	.7678	.9012	1.051	1.222	1.419	1.651	2.280	3.405	.20
.25	.35993	.4510	.5506	.6600	.7810	.9158	1.067	1.240	1.439	1.672	2.305	3.435	.25
.30	.36700	.4595	.5604	.6713	.7937	.9300	1.083	1.257	1.457	1.693	2.329	3.464	.30
.35	.37379	.4676	.5699	.6821	.8060	.9437	1.098	1.274	1.476	1.713	2.353	3.492	.35
.40	.38033	.4755	.5791	.6927	.8179	.9570	1.113	1.290	1.494	1.732	2.376	3.520	.40
.45	.38665	.4831	.5880	.7029	.8295	.9700	1.127	1.308	1.511	1.751	2.399	3.547	.45
.50	.39276	.4904	.5967	.7129	.8408	.9826	1.141	1.321	1.528	1.770	2.421	3.575	.50
.55	.39870	.4976	.6051	.7225	.8517	.9950	1.155	1.337	1.545	1.788	2.443	3.601	.55
.60	.40447	.5045	.6133	.7320	.8625	1.007	1.169	1.351	1.561	1.806	2.465	3.628	.60
.65	.41008	.5114	.6213	.7412	.8729	1.019	1.182	1.366	1.577	1.824	2.486	3.654	.65
.70	.41555	.5180	.6291	.7502	.8832	1.030	1.195	1.380	1.593	1.841	2.507	3.679	.70
.75	.42090	.5245	.6367	.7590	.8932	1.042	1.207	1.394	1.608	1.858	2.528	3.705	.75
.80	.42612	.5308	.6441	.7676	.9031	1.053	1.220	1.408	1.624	1.875	2.548	3.730	.80
.85	.43122	.5370	.6515	.7761	.9127	1.064	1.232	1.422	1.639	1.892	2.568	3.754	.85
.90	.43622	.5430	.6586	.7844	.9222	1.074	1.244	1.435	1.653	1.908	2.588	3.779	.90
.95	.44112	.5490	.6656	.7925	.9314	1.085	1.255	1.448	1.668	1.924	2.607	3.803	.95
	.0048	.0056	.0066	.0080	.0092	.010	.012	.013	.014	.016	0.019	.024	
1.00	.44592	.5548	.6724	.8005	.9406	1.095	1.267	1.461	1.682	1.940	2.626	3.827	1.00

For all values $0 \le \gamma \le 1$, $\lambda(0,\gamma) = 0$.

In Table 2, which applies to censored samples, $\lambda(h, \gamma)$ is given for $h = 0.01(0.01)$ $0.10(0.05)$ $0.70(0.10)$ 0.90 and for $\gamma = 0.00(0.05)$ 1.00. This represents a considerable enlargement of the original table which was limited to entries for which $h \le 0.50$. For any given censored sample, after computing $\hat{\gamma} = s^2/(\bar{x} - x_0)^2$ or $\hat{\gamma} = s^2/(\bar{x} - x_n)^2$ and $h = (N - n)/N$, enter table 2 with these values of the two arguments to obtain $\hat{\lambda} = \lambda(h, \hat{\gamma})$ using two-way interpolation. Here again linear interpolation should be sufficiently accurate for most requirements. With $\hat{\lambda}$ thus determined, the required estimates follow from (2) or from (3), the choice of equations depending on sample type.

The asymptotic variances and covariances may be calculated as

$$V(\hat{\mu}) \sim \frac{\sigma^2}{N}\mu_{11}, \qquad \mathrm{Cov}(\hat{\mu}, \hat{\sigma}) \sim \frac{\sigma^2}{N}\mu_{12},$$
$$V(\hat{\sigma}) \sim \frac{\sigma^2}{N}\mu_{22}, \qquad \rho_{\hat{\mu},\hat{\sigma}} \sim \frac{\mu_{12}}{\sqrt{\mu_{11}\mu_{22}}}, \tag{5}$$

where the μ_{ij} above arc
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Table 3. VARIANCE

η	For Truncated	
	μ_{11}	μ_{12}
-4.0	1.00054	-.001143
-3.5	1.00313	-.005922
-3.0	1.01460	-.024153
-2.5	1.05738	-.081051
-2.4	1.07437	-.101368
-2.3	1.09604	-.126136
-2.2	1.12365	-.156229
-2.1	1.15880	-.192688
-2.0	1.20350	-.236743
-1.9	1.26030	-.289860
-1.8	1.33246	-.353771
-1.7	1.42405	-.430531
-1.6	1.54024	-.522564
-1.5	1.68750	-.632733
-1.4	1.87398	-.764405
-1.3	2.10982	-.921533
-1.2	2.40764	-1.10874
-1.1	2.78311	-1.33145
-1.0	3.25557	-1.59594
-0.9	3.84879	-1.90952
-0.8	4.59189	-2.28066
-0.7	5.52036	-2.71911
-0.6	6.67730	-3.23612
-0.5	8.11482	-3.84458
-0.4	9.89562	-4.55921
-0.3	12.0949	-5.39683
-0.2	14.8023	-6.37653
-0.1	18.1244	-7.51996
0.0	22.1875	-8.85155
0.1	27.1403	-10.3988
0.2	33.1573	-12.1927
0.3	40.4428	-14.2679
0.4	49.2342	-16.6628
0.5	59.8081	-19.4208
0.6	72.4834	-22.5896
0.7	87.6276	-26.2220
0.8	105.66	-30.376
0.9	127.07	-35.117
1.0	152.40	-40.515
1.1	182.29	-46.650
1.2	217.42	-53.601
1.3	258.61	-61.465
1.4	306.78	-70.347
1.5	362.91	-80.350
1.6	428.11	-91.586
1.7	503.57	-104.17
1.8	591.03	-118.31
1.9	691.78	-134.10
2.0	807.71	-151.73
2.1	940.38	-171.30
2.2	1091.4	-192.92
2.3	1265.4	-217.17
2.4	1458.6	-243.23
2.5	1677.8	-271.99

When truncation or type I
ing to $\eta = \xi$ are applic
entries corresponding to
type II left censored and
Percent Restriction = 100

where the μ_{ij} above are so defined that the expressions of (5) equal the corresponding expressions given in [1].

In order to permit ready evaluation of the μ_{ij} of (5), and thereby simplify the calculation of asymptotic variances and covariances, Table 3 has been added. (Various less extensive tables giving certain of the entries included in Table 3 have previously been published by Bliss [3], Gupta [4], Hald [5], and Cohen and Woodward [2]. Credit for the Bliss tables relating to censored samples, which were the first of these to appear, was inadvertently attributed to W. L. Stevens both by Hald [5] and by the writer [1]. It has recently been learned that while Stevens derived the formulas involved, computation of the tables

Table 3. VARIANCE FACTORS FOR SINGLY TRUNCATED AND SINGLY CENSORED SAMPLES

η	For Truncated Samples				For Censored Samples				Percent Rest.	η
	μ_{11}	μ_{12}	μ_{22}	ρ	μ_{11}	μ_{12}	μ_{22}	ρ		
-4.0	1.00054	-.001143	.502287	-.001613	1.00000	-.000006	.500030	-.000001	0.00	-4.0
-3.5	1.00313	-.005922	.510366	-.008277	1.00001	-.000052	.500208	-.000074	0.02	-3.5
-3.0	1.01460	-.024153	.536283	-.032744	1.00010	-.000335	.501180	-.000473	0.13	-3.0
-2.5	1.05738	-.081051	.602029	-.101586	1.00056	-.001712	.505280	-.002407	0.62	-2.5
-2.4	1.07437	-.101368	.622786	-.123924	1.00078	-.002312	.506935	-.003247	0.82	-2.4
-2.3	1.09604	-.126136	.646862	-.149803	1.00107	-.003099	.509030	-.004341	1.07	-2.3
-2.2	1.12365	-.156229	.674663	-.179434	1.00147	-.004121	.511658	-.005757	1.39	-2.2
-2.1	1.15880	-.192688	.706637	-.212937	1.00200	-.005438	.514926	-.007571	1.79	-2.1
-2.0	1.20350	-.236743	.743283	-.250310	1.00270	-.007123	.518960	-.009875	2.28	-2.0
-1.9	1.26030	-.289860	.785158	-.291398	1.00363	-.009266	.523899	-.012778	2.87	-1.9
-1.8	1.33246	-.353771	.832880	-.335818	1.00485	-.011971	.529899	-.016405	3.59	-1.8
-1.7	1.42405	-.430531	.887141	-.383041	1.00645	-.015368	.537141	-.020901	4.46	-1.7
-1.6	1.54024	-.522564	.948713	-.432293	1.00852	-.019610	.545827	-.026431	5.48	-1.6
-1.5	1.68750	-.632733	1.01846	-.482644	1.01120	-.024884	.556186	-.033181	6.68	-1.5
-1.4	1.87398	-.764405	1.09734	-.533054	1.01467	-.031410	.568471	-.041358	8.08	-1.4
-1.3	2.10982	-.921533	1.18642	-.582464	1.01914	-.039460	.582981	-.051193	9.68	-1.3
-1.2	2.40764	-1.10874	1.28690	-.629889	1.02488	-.049355	.600046	-.062937	11.51	-1.2
-1.1	2.78311	-1.33145	1.40009	-.674498	1.03224	-.061491	.620049	-.076861	13.57	-1.1
-1.0	3.25557	-1.59594	1.52746	-.715676	1.04168	-.076345	.643438	-.093252	15.87	-1.0
-0.9	3.84879	-1.90952	1.67064	-.753044	1.05376	-.094501	.670724	-.112407	18.41	-0.9
-0.8	4.59189	-2.28066	1.83140	-.786452	1.06923	-.116674	.702513	-.134620	21.19	-0.8
-0.7	5.52036	-2.71911	2.01172	-.815942	1.08904	-.143744	.739515	-.160175	24.20	-0.7
-0.6	6.67730	-3.23612	2.21376	-.841703	1.11442	-.176798	.782574	-.189317	27.43	-0.6
-0.5	8.11482	-3.84458	2.43990	-.864019	1.14696	-.217183	.832691	-.222233	30.85	-0.5
-0.4	9.89562	-4.55921	2.69271	-.883229	1.18876	-.266577	.891077	-.259011	34.46	-0.4
-0.3	12.0949	-5.39683	2.97504	-.899688	1.24252	-.327080	.959181	-.299607	38.21	-0.3
-0.2	14.8023	-6.37653	3.28997	-.913744	1.31180	-.401326	1.03877	-.343800	42.07	-0.2
-0.1	18.1244	-7.51996	3.64083	-.925727	1.40127	-.492641	1.13198	-.391156	46.02	-0.1
0.0	22.1875	-8.85155	4.03126	-.935932	1.51709	-.605233	1.24145	-.441013	50.00	0.0
0.1	27.1403	-10.3988	4.46517	-.944623	1.66743	-.744459	1.37042	-.492483	53.98	0.1
0.2	33.1573	-12.1927	4.94678	-.952028	1.86310	-.917165	1.52288	-.544498	57.93	0.2
0.3	40.4428	-14.2679	5.48069	-.958345	2.11857	-1.13214	1.70381	-.595891	61.79	0.3
0.4	49.2342	-16.6628	6.07169	-.963742	2.45318	-1.40071	1.91942	-.645504	65.54	0.4
0.5	59.8081	-19.4208	6.72512	-.968361	2.89293	-1.73757	2.17751	-.692299	69.15	0.5
0.6	72.4834	-22.5896	7.44658	-.972322	3.47293	-2.16185	2.48793	-.735459	72.57	0.6
0.7	87.6276	-26.2220	8.24204	-.975727	4.24075	-2.69858	2.86318	-.774443	75.80	0.7
0.8	105.66	-30.376	9.1178	-.97866	5.2612	-3.3807	3.3192	-.80899	78.81	0.8
0.9	127.07	-35.117	10.081	-.98119	6.6229	-4.2517	3.8765	-.83912	81.59	0.9
1.0	152.40	-40.515	11.138	-.98338	8.4477	-5.3696	4.5614	-.86502	84.13	1.0
1.1	182.29	-46.650	12.298	-.98529	10.903	-6.8116	5.4082	-.88703	86.43	1.1
1.2	217.42	-53.601	13.567	-.98694	14.224	-8.6918	6.4616	-.90557	88.49	1.2
1.3	258.61	-61.465	14.954	-.98838	18.735	-11.121	7.7804	-.92109	90.32	1.3
1.4	306.78	-70.347	16.471	-.98964	24.892	-14.319	9.4423	-.93401	91.92	1.4
1.5	362.91	-80.350	18.124	-.99074	33.339	-18.539	11.550	-.94473	93.32	1.5
1.6	428.11	-91.586	19.922	-.99171	44.986	-24.139	14.243	-.95361	94.52	1.6
1.7	503.57	-104.17	21.874	-.99256	61.132	-31.616	17.706	-.96097	95.54	1.7
1.8	591.03	-118.31	24.003	-.99332	83.638	-41.664	22.193	-.96706	96.41	1.8
1.9	691.78	-134.10	26.311	-.99398	115.19	-55.252	28.046	-.97211	97.13	1.9
2.0	807.71	-151.73	28.813	-.99457	159.66	-73.750	35.740	-.97630	97.72	2.0
2.1	940.38	-171.30	31.511	-.99509	222.74	-99.100	45.930	-.97979	98.21	2.1
2.2	1091.4	-192.92	34.405	-.99555	312.73	-134.08	59.526	-.98270	98.61	2.2
2.3	1265.4	-217.17	37.575	-.99596	441.92	-182.68	77.810	-.98514	98.93	2.3
2.4	1458.6	-243.23	40.858	-.99632	628.58	-250.68	102.59	-.98718	99.18	2.4
2.5	1677.8	-271.99	44.392	-.99665	899.99	-346.53	136.44	-.98890	99.38	2.5

When truncation or type I censoring occurs on the left, entries in this table corresponding to $\eta = \xi$ are applicable. For right truncated or type I right censored samples, read entries corresponding to $\eta = -\xi$, but delete negative signs from μ_{12} and ρ. For both type II left censored and type II right censored samples, read entries corresponding to Percent Restriction = 100h, but for right censoring delete negative signs from μ_{12} and ρ.

was the work of Bliss.) For any given truncated or type I censored sample, after calculating $\hat{\xi} = (x_0 - \hat{\mu})/\hat{\sigma}$, enter the appropriate columns of table 3 with $\hat{\eta} = \hat{\xi}$ if the restriction is on the left or with $\hat{\eta} = -\hat{\xi}$ if the restriction is on the right, and interpolate to obtain the required values of the μ_{ij}. For type II censored samples, enter table 3 through the Percent Restricted column with Percent Restricted $= 100h$ and interpolate to obtain the required values of the μ_{ij}. In all cases when restriction is on the left, the negative signs affixed to entries for μ_{12} and ρ are retained, but are to be deleted for right restricted samples. With the μ_{ij} thus evaluated, the asymptotic variances and covariances may be approximated using (5) with σ^2 replaced by its estimate $\hat{\sigma}^2$.

To illustrate the ease with which the tables presented here may be employed in practical situations, we select two examples that were previously considered in [1].

Left truncated sample. Data for this sample, which was given in [1] as example 1, are summarized as follows: $\bar{x} = 0.124624$, $s^2 = 2.1106 \times 10^{-6}$, $x_0 = 0.1215$ and $n = 100$. It follows that $\hat{\gamma} = s^2/(\bar{x} - x_0)^2 = 0.21627$ and linear interpolation in table 1 immediately yields $\hat{\theta} = 0.03012$ which is in exact agreement with the value previously obtained in [1]. Using (1), we then compute $\hat{\mu} = 0.1245$, $\hat{\sigma}^2 = 2.405 \times 10^{-6}$, and $\hat{\sigma} = 0.00155$. For the variances and covariance, we enter table 3 with $\hat{\xi} = (x_0 - \hat{\mu})/\hat{\sigma} = -1.94$, and interpolate linearly to obtain $\mu_{11} = 1.2376$, $\mu_{12} = -0.26861$, $\mu_{22} = 0.76841$, and $\rho_{\hat{\mu},\hat{\sigma}} = -0.2750$. Note that μ_{12} and $\rho_{\hat{\mu},\hat{\sigma}}$ are negative since this sample is left restricted. When these values are substituted into (5), and σ^2 is replaced by its estimate $\hat{\sigma}^2 = 2.405 \times 10^{-6}$, the variances and covariance follow immediately as $V(\hat{\mu}) \doteq 2.98 \times 10^{-8}$, $V(\hat{\sigma}) \doteq 1.85 \times 10^{-8}$, and Cov $(\hat{\mu}, \hat{\sigma}) \doteq -0.65 \times 10^{-8}$, in agreement with the results obtained in [1]. Here, however, the necessary computational effort has been substantially reduced from that originally required.

Right Censored Type II Sample. Data for this sample which was given in [1] as example 6 and which was originally given by Gupta [4], are summarized as: $\bar{x} = 1{,}304.832$, $s^2 = 12{,}128.250$, $x_n = 1{,}450.000$, $N = 300$, and $n = 119$. It follows that $\hat{\gamma} = s^2/(\bar{x} - x_n)^2 = 0.575515$ and $h = 181/300 = 0.6033$. Two-way linear interpolation in table 2 immediately yields $\hat{\lambda} = 1.36$. Using (3), we then compute $\hat{\mu} = 1{,}502$, $\hat{\sigma}^2 = 40{,}789$, and $\hat{\sigma} = 202$. For the variances and covariances, we enter table 3 with Percent Restriction $= 100h = 60.33$ and interpolate linearly to obtain $\mu_{11} = 2.022$, $\mu_{12} = 1.051$, $\mu_{22} = 1.635$ and $\rho_{\hat{\mu},\hat{\sigma}} = 0.576$. Note that here μ_{12} and $\rho_{\hat{\mu},\hat{\sigma}}$ are positive since in this example the restriction is on the right side. Using the values determined above with $\hat{\sigma}^2 = 40{,}789$ substituted for σ^2, the variances and covariance follow from (5) as $V(\hat{\mu}) \doteq 274.9$, $V(\hat{\sigma}) \doteq 222.3$, and Cov $(\hat{\mu}, \hat{\sigma}) \doteq 142.9$. Except for errors in the signs of μ_{12}, and $\rho_{\hat{\mu},\hat{\sigma}}$ which occur in [1], the results obtained here agree with the more laboriously computed results of the former paper.

The assistance of Mr. Robert Everett and Mr. David Lifsey, who performed most of the computations involved in preparing these tables, is gratefully acknowledged.

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A.4.5

AMSTED INDUSTRIES
INCORPORATED

44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482
TELECOPIER (312) 819-8484

December 21, 1995

Mr. Ken Bardle
U.S. EPA Region V
HRE-8J
77 W. Jackson Blvd.
Chicago, IL 60604

RE: Letter for Chief Financial Officer
to Demonstrate Liability Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance OH 44601
EPA I.D.# OHD 017497587
EPA I.D.# OHD 981090418

Dear Mr. Bardle:

Enclosed is a December 14, 1995 letter signed by Mr. G.B. Montgomery whereby AMSTED Industries Incorporated is demonstrating financial responsibility for liability coverage and closure and post-closure care for the subject owned facilities. Also enclosed is the certifying letter from Price Waterhouse, AMSTED's independent auditor.

This information is being submitted as required under the consent decree in U.S. v. AMSTED, civil action C87-1284A, Section C., paragraph 6 and Section D., paragraph 4. This information has also been submitted to the USEPA Region V RCRA Enforcement Branch and the Ohio EPA, Division of Solid and Hazardous Waste offices in Columbus and Twinsburg, Ohio.

Please address all inquiries in this matter to the undersigned. A December 20, 1994 transmittal letter to U.S. EPA was returned to our office unopened.

Sincerely,

Edward J. Brosius

Edward J. Brosius
Assistant General Counsel
& Assistant Secretary

EJB/mlg
Enclosure
cc: B. Wellman
FinResp\ASFAllia.104

Amsted
INDUSTRIES

AMSTED INDUSTRIES
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LAW DEPARTMENT

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December 14, 1995

Director of the Ohio
Environmental Protection Agency
P.O. Box 1049
1800 Watermark Drive
Columbus, Ohio 43266-0149

RE: Letter for Chief Financial Officer
to Demonstrate Liability and Closure/Post Closure Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance, Ohio 44601
EPA I.D. #OHD 981090418 and

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D. # OHD 017497587

Dear Sir:

I am the chief financial officer of AMSTED Industries Incorporated; 205 North Michigan Avenue; Chicago, Illinois 60601. This letter is in support of the use of the financial test to demonstrate financial responsibility for liability coverage and closure care as specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code.

The firm identified above is the owner or operator of the following facilities for which liability coverage for both sudden and nonsudden accidental occurrences is being demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code:

Proposed Mount Athos Landfill
Griffin Pipe Products Company
Adams Street
P.O. Box 740
Lynchburg, VA 24505

American Steel Foundries
1001 East Broadway
Alliance, Ohio 44601
EPA I.D.# OHD 981090418

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D.# OHD 017497587

Diamond Chain Company
402 Kentucky Avenue
Indianapolis, IN 46207
EPA I.D.# IND 006067880

Griffin Pipe Products Company
Adams Street-Upper Basin
Lynchburg, VA 24501
EPA I.D.# VAD 065417008

Griffin Pipe Products Company
1100 West Front Street
Florence, NJ 08518
EPA I.D. # NJD 003951985

The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 through 3745-55-51 and 3745-66-40 through 3745-66-48 of the Administrative Code, liability coverage for both sudden and nonsudden accidental occurrences at the following facilities owned or operated by the following: The firm identified above is the direct or higher-tier parent corporation of the owner or operator: None

1. The firm identified above owns or operates the following facilities for which financial assurance for closure or post-closure care or liability coverage is demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimate covered by the test are shown for each facility:

Mount Athos Closure Cost	$ 2,023,400
Mount Athos Post-Closure Cost	$ 639,000
ASF Sebring Closure Cost	$ 1,694,055
ASF Sebring Post-Closure Cost	$ 350,000

ASF Alliance Areas A & B Closure Cost	$	30,000
DC Indianapolis Closure Cost	$	61,000
GPP Lynchburg Closure Cost	$	5,591

2. The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code, the closure and post-closure care or liability coverage of the following facilities owned or operated by the guaranteed party. The current cost estimates for the closure or post-closure so guaranteed are shown for each facility: None

3. The firm identified above is demonstrating financial assurance for the closure or post-closure care of the following facilities through the use of a test equivalent or substantially equivalent to the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 and 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates covered by such a test are shown for each facility: None

4. The firm identified above owns or operates the following hazardous waste management facilities for which financial assurance for closure or, if a disposal facility, post-closure care, is not demonstrated to the director through the financial test or any other financial assurance mechanisms specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates not covered by such financial assurance are shown for each facility: None

5. This firm is the owner or operator of the following UIC facilities for which financial assurance for plugging and abandonment is required under Chapter 3745-34 of the Administrative Code. The current closure cost estimates as required by Chapters 3745-34, 3745-55 and 3745-66 of the Administrative Code are shown for each facility: None

This firm is not required to file a Form 10K with the securities and exchange commission (SEC) for the latest fiscal year.

The fiscal year of this firm ends on September 30. The figures for the following items marked with an asterisk are derived from the firm's independently audited, year-end financial statements for the latest completed fiscal year, ended September 30, 1995.

Part B. Closure and Post-Closure Care and Liability Coverage

1. Sum of current closure and post-closure cost estimates (total of all cost estimates listed above). $ 4,803,046

2.	Amount of annual aggregate liability coverage to be demonstrated.	$ 8,000,000
3.	Sum of lines 1 and 2.	$ 12,803,046
*4.	Total liabilities (if any portion of your closure or post-closure cost estimates is included in your total liabilities, you may deduct that portion from this line and add that amount to lines 5 and 6).	$437,429,000
*5.	Tangible net worth.	$294,076,000
*6.	Net worth.	$303,763,000
*7.	Current assets.	$433,361,000
*8.	Current liabilities.	$166,769,000
9.	Net working capital (line 7 minus line 8).	$266,592,000
*10.	The sum of net income plus depreciation, depletion, and amortization.	$82,847,000
*11.	Total assets in U.S. (required only if less than 90% of assets are located in the U.S.).	$663,656,000
12.	Is line 5 at least $10 million?	YES
13.	Is line 5 at least 6 times line 3?	YES
14.	Is line 9 at least 6 times line 3?	YES
*15.	Are at least 90% of assets located in the U.S. If not, complete line 16.	NO
16.	Is line 11 at least 6 times line 3?	YES

NEED TWO OF THREE

17. Is line 4 divided by line 6 less than 2.0? YES

18. Is line 10 divided by line 4 greater than 0.1? YES

19. Is line 7 divided by line 8 greater than 1.5? YES

I hereby certify that the wording of this letter is identical to the wording specified in paragraph (G) of rule 3745-55-51 of the Administrative Code as such regulations were constituted on the date shown immediately below.

Gary B. Montgomery
Vice President

12/14/95
Date

200 East Randolph Drive
Chicago, IL 60601

Telephone 312 540 1500

Price Waterhouse LLP

Report of Independent Accountants

December 20, 1995

To the Board of Directors of
AMSTED Industries Incorporated

We have audited, in accordance with generally accepted auditing standards, the consolidated balance sheet of AMSTED Industries Incorporated (AMSTED) and its subsidiaries as of September 30, 1995 and 1994 and the related consolidated statements of results of operations and of cash flows for each of the three years in the period ended September 30, 1995 (the Financial Statements), and have issued our report thereon dated October 25, 1995.

At your request, we have compared the amounts of current assets ($433,361,000), current liabilities ($166,769,000), total liabilities ($437,429,000), net worth ($303,763,000) and total assets in the U.S. ($663,656,000) included in the letter to the Director of the Ohio Environmental Protection Agency, dated December 14, 1995 and signed by Mr. Gary B. Montgomery, AMSTED's Vice President and Chief Financial Officer (the Letter), to the amounts included in the Financial Statements and found them to be in agreement. We have subtracted the amount of intangible assets from the amount of net worth included in the Financial Statements and compared the difference to the amount shown as tangible net worth ($294,076,000) in the Letter and found it to be in agreement. We have added the amount of net income to the amount of depreciation, depletion and amortization included in the Financial Statements and compared the sum to the amounts shown as item 10 in the Letter ($82,847,000) and found it to be in agreement.

Because the above procedures do not constitute an audit made in accordance with generally accepted auditing standards, we do not express an opinion on any of the amounts referred to above. Had we performed additional procedures or had we conducted an audit of the information contained in the Letter in accordance with generally accepted auditing standards, matters might have come to our attention that would have been reported to you.

This report is intended solely for the information and use of the Board of Directors and management of AMSTED Industries Incorporated and the Director of the Ohio Environmental Protection Agency.

Price Waterhouse LLP

AMSTED INDUSTRIES
INCORPORATED
44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482
TELECOPIER (312) 819-8484

February 14, 1995

Mr. Ken Bardle
U.S. EPA Region V
HRE-8J
77 W. Jackson Blvd.
Chicago, IL 60604

RECEIVED
FEB 15 1995
OFFICE OF RCRA
WASTE MANAGEMENT DIVISION
EPA, REGION V

RE: Letter for Chief Financial Officer
to Demonstrate Liability Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance OH 44601
EPA I.D.# OHD 017497587
EPA I.D.# OHD 981090418

Dear Mr. Bardle:

Enclosed is a December 15, 1994 letter signed by Mr. G.B. Montgomery whereby AMSTED Industries Incorporated is demonstrating financial responsibility for liability coverage and closure and post-closure care for the subject owned facilities. Also, enclosed is the certifying letter from Price Waterhouse, AMSTED's independent auditor, and the printed copy of AMSTED's fiscal 1994 annual report.

This information is being submitted as required under the consent decree in U.S. v. AMSTED, civil action C87-1284A, Section C., paragraph 6 and Section D., paragraph 4. This information has also been submitted to the USEPA Region V RCRA Enforcement Branch and the Ohio EPA, Division of Solid and Hazardous Waste offices in Columbus and Twinsburg, Ohio.

Please address all inquiries in this matter to the undersigned. A December 20, 1994 transmittal letter to U.S. EPA was returned to our office unopened.

Sincerely,

Edward J. Brosius

Edward J. Brosius
Assistant General Counsel
& Assistant Secretary

EJB/kda
FinResp\ASFAllia.104
Enclosures
cc: B. Wellman

Amsted
INDUSTRIES

200 East Randolph Drive
Chicago, IL 60601

Telephone 312 540 1500

Price Waterhouse LLP

December 20, 1994

To the Board of Directors of
AMSTED Industries Incorporated

We have audited, in accordance with generally accepted auditing standards, the consolidated statement of financial position of AMSTED Industries Incorporated (AMSTED) and its subsidiaries as of September 30, 1994 and the related consolidated statements of results of operations and of cash flows for the fiscal year then ended, and have issued our report thereon dated October 19, 1994.

At your request, we have compared the amounts of current assets ($384,500,000), current liabilities ($155,361,000), total liabilities ($432,207,000), net worth ($249,091,000) and assets located in the U.S. ($612,032,000) included in the letter to the Director of the Ohio Environmental Protection Agency, dated December 15, 1994 and signed by Mr. Gary B. Montgomery, AMSTED's Vice President and Chief Financial Officer, to the amounts included in the aforementioned financial statements and found them to be in agreement. We have subtracted the amount of tangible assets from the amount of net worth included in the aforementioned financial statements and compared the difference to the amount indicated as tangible net worth ($238,230,000) in Mr. Montgomery's letter and found it to be in agreement. We have added the amount of net loss to the amount of depreciation, depletion and amortization included in the aforementioned financial statements and compared the sum to the amounts indicated in item 10 (($13,597,000)), ($65,310,000 before the cumulative effect of accounting changes).

The above agreed-upon procedures are substantially less in scope than an audit, the objective of which is the expression of an opinion on the information contained in the above referenced letter. Accordingly, we do not express such an opinion.

In connection with these procedures, nothing came to our attention that caused us to believe that the amounts of current assets, current liabilities, total liabilities, net worth, assets located in the U.S., tangible net worth and the sum of net loss, depreciation, depletion and amortization (both before and after the cumulative effect of accounting changes) included in the December 15, 1994 letter signed by Mr. Montgomery should be adjusted. Had we performed additional procedures or had we made an audit of the information contained in the above referenced letter, other matters might have come to our attention that would have been reported to you.

December 20, 1994
The Board of Directors of
AMSTED Industries Incorporated

This report is intended solely for the information and use of the Board of Directors and management of AMSTED Industries Incorporated and the Director of the Ohio Environmental Protection Agency.

Price Waterhouse LLP

AMSTED INDUSTRIES

INCORPORATED

44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8409
TELECOPIER (312) 819-8484

December 15, 1994

Director of the Ohio
Environmental Protection Agency
P.O. Box 1049
1800 Watermark Drive
Columbus, Ohio 43266-0149

RE: Letter for Chief Financial Officer
to Demonstrate Liability and Closure/Post Closure Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance, Ohio 44601
EPA I.D. #OHD 981090418 and

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D. # OHD 017497587

Dear Sir:

I am the chief financial officer of AMSTED Industries Incorporated; 205 North Michigan Avenue; Chicago, Illinois 60601. This letter is in support of the use of the financial test to demonstrate financial responsibility for liability coverage and closure care as specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code.

The firm identified above is the owner or operator of the following facilities for which liability coverage for both sudden and nonsudden accidental occurrences is being demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code:

Proposed Mount Athos Landfill
Griffin Pipe Products Company
Adams Street
P.O. Box 740
Lynchburg, VA 24505

American Steel Foundries
1001 East Broadway
Alliance, Ohio 44601
EPA I.D.# OHD 981090418

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D.# OHD 017497587

Diamond Chain Company
402 Kentucky Avenue
Indianapolis, IN 46207
EPA I.D.# IND 006067880

Griffin Pipe Products Company
Adams Street-Upper Basin
Lynchburg, VA 24501
EPA I.D.# VAD 065417008

Griffin Pipe Products Company
1100 West Front Street
Florence, NJ 08518
EPA I.D. # NJD 003951985

The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 through 3745-55-51 and 3745-66-40 through 3745-66-48 of the Administrative Code, liability coverage for both sudden and nonsudden accidental occurrences at the following facilities owned or operated by the following: The firm identified above is the direct or higher-tier parent corporation of the owner or operator: None

1. The firm identified above owns or operates the following facilities for which financial assurance for closure or post-closure care or liability coverage is demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimate covered by the test are shown for each facility:

Mount Athos Closure Cost	$ 1,945,600
Mount Athos Post-Closure Cost	$ 614,400
ASF Sebring Closure Cost	$ 1,550,050
ASF Sebring Post-Closure Cost	$ 1,056,000

ASF Alliance EAF Baghouse Area Closure Cost	$	85,000
ASF Alliance Areas A & B Closure Cost	$	30,000
DC Indianapolis Closure Cost	$	55,000
GPP Lynchburg Closure Cost	$	5,376

2. The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code, the closure and post-closure care or liability coverage of the following facilities owned or operated by the guaranteed party. The current cost estimates for the closure or post-closure so guaranteed are shown for each facility: None

3. The firm identified above is demonstrating financial assurance for the closure or post-closure care of the following facilities through the use of a test equivalent or substantially equivalent to the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 and 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates covered by such a test are shown for each facility: None

4. The firm identified above owns or operates the following hazardous waste management facilities for which financial assurance for closure or, if a disposal facility, post-closure care, is not demonstrated to the director through the financial test or any other financial assurance mechanisms specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates not covered by such financial assurance are shown for each facility: None

5. This firm is the owner or operator of the following UIC facilities for which financial assurance for plugging and abandonment is required under Chapter 3745-34 of the Administrative Code. The current closure cost estimates as required by Chapters 3745-34, 3745-55 and 3745-66 of the Administrative Code are shown for each facility: None

This firm is not required to file a Form 10K with the securities and exchange commission (SEC) for the latest fiscal year.

The fiscal year of this firm ends on September 30. The figures for the following items marked with an asterisk are derived from the firm's independently audited, year-end financial statements for the latest completed fiscal year, ended September 30, 1994.

Part B. Closure and Post-Closure Care and Liability Coverage

1. Sum of current closure and post-closure cost estimates (total of all cost estimates listed above). $ 5,341,426

2.	Amount of annual aggregate liability coverage to be demonstrated.	$ 8,000,000
3.	Sum of lines 1 and 2.	$ 13,341,426
*4.	Total liabilities (if any portion of your closure or post-closure cost estimates is included in your total liabilities, you may deduct that portion from this line and add that amount to lines 5 and 6).	$432,207,000
*5.	Tangible net worth.	$238,230,000
*6.	Net worth.	$249,091,000
*7.	Current assets.	$384,500,000
*8.	Current liabilities.	$155,361,000
9.	Net working capital (line 7 minus line 8).	$229,139,000
*10.	The sum of net income plus depreciation, depletion, and amortization.	($13,597,000)[1]
	[1] $65,310,000 Based on income before cumulative effect of accounting changes.	
*11.	Total assets in U.S. (required only if less than 90% of assets are located in the U.S.).	$612,032,000
12.	Is line 5 at least $10 million?	YES
13.	Is line 5 at least 6 times line 3?	YES
14.	Is line 9 at least 6 times line 3?	YES
*15.	Are at least 90% of assets located in the U.S. If not, complete line 16.	No
16.	Is line 11 at least 6 times line 3?	Yes

NEED TWO OF THREE

17.	Is line 4 divided by line 6 less than 2.0?	YES
18.	Is line 10 divided by line 4 greater than 0.1?	No
19.	Is line 7 divided by line 8 greater than 1.5?	YES

I hereby certify that the wording of this letter is identical to the wording specified in paragraph (G) of rule 3745-55-51 of the Administrative Code as such regulations were constituted on the date shown immediately below.

Gary B. Montgomery
Vice President

12/15/94

Date

OhioEPA

State of Ohio Environmental Protection Agency

P.O. Box 1049, 1800 WaterMark Dr.
Columbus, Ohio 43266-0149
(614) 644-3020
FAX (614) 644-2329

TRACKING - DHWM, CM&ES
TO GO ON: ✓ RCRIS __ FO LOG __ USEPA LOG __ CJ LOG __ FILE
VK ENTERED: ✓ RCRIS __ FO LOG __ USEPA LOG __ CJ LOG ONLY
RCRIS ENTRY CODES: (EVALUATION) O11 (ENFORCEMENT)____
CEI __ CI __ OTHER FRR INITIAL NOV __ FOLLOW-UP NOV __
FULL RTC __ PARTIAL RTC __ LDR __ SENT TO USEPA: YES__ NO__

Donald R. Schregardus
Director

January 25, 1994

Re: **Amsted Industries, Inc.**
Alliance facility OHD987090418 011
Sebring facility OHD017497587 013

Edward J. Brosius
Assistant General Counsel &
Assistant Secretary
Amsted Industries, Inc.
44th Floor Boulevard Towers South
Chicago, Illinois 60601

Dear Mr. Brosius:

On January 18, 1994 Ohio EPA conducted a review of the financial assurance documentation on file for the Amsted Industries' Alliance and Sebring landfill facilities referenced above. The facilities were evaluated for compliance with the closure/post-closure cost estimate, financial assurance for closure/post-closure, as well as liability coverage requirements for sudden and non-sudden accidental occurrences as set forth in Ohio Administrative Code (OAC) rules 3745-66-42 through 3745-66-45 and 3745-66-47. Specifically, the Sebring facility (OHD017497587) is required to meet the post-closure financial assurance requirements.

Furthermore, the Sebring facility was evaluated for compliance with the financial assurance related conditions set forth in Section V.D.4 of the Consent Order, United States v. Amsted Industries, Inc. d/b/a American Steel Foundries, Civil No. C87-1284A, entered into December 1, 1992. The Consent Order required Amsted Industries to submit to U.S. EPA and Ohio EPA certification that Amsted Industries has established financial assurance for closure and post-closure care of and liability coverage for the Sebring facility in accordance with 40 C.F.R. 265.143 through 265.145 and 265.147 and OAC rules 3745-66-43 through 3745-66-47.

In addition, the Alliance facility was evaluated for compliance with the financial assurance related conditions set forth in Section VI, of the Consent Order, State of Ohio v. Amsted Industries d/b/a American Steel Foundries, Case No. 93-CV01107 entered into July 12, 1993 in the Stark County Court of Common Pleas. The Consent Order required Amsted Industries to submit a detailed closure cost estimate for the Alliance facility which included areas A and B, as well as demonstrate financial responsibility for closure and liability coverage, in accordance with OAC rules 3745-66-42, 3745-66-43 and 3745-66-47.

RECEIVED JAN 11 1994
WMD RCRA
RECORD CENTER

AMSTED INDUSTRIES

INCORPORATED

A.4.5

44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482
TELECOPIER (312) 819-8484

December 23, 1993

Chief, RCRA Enforcement Branch, 5HR-12
U.S. EPA Region V
77 W. Jackson Blvd.
Chicago, IL 60604
Attn: Kimberly Ogle

RECEIVED
JAN 5
OFFICE OF RCRA
WASTE MANAGEMENT DIV
EPA, REGION

RE: Letter for Chief Financial Officer
to Demonstrate Liability Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance OH 44601
EPA I.D.# OHD 017497587
EPA I.D.# OHD 987090418

Dear Ms. Ogle:

Enclosed is a December 17, 1993 letter signed by Mr. G.K. Walter whereby AMSTED Industries Incorporated is demonstrating financial responsibility for liability coverage and closure and post-closure care for the subject owned facilities. Also, enclosed is the certifying letter from Price Waterhouse, AMSTED's independent auditor, and the printed copy of AMSTED's fiscal 1993 annual report.

This information is being submitted as required under the consent decree in U.S. v. AMSTED, civil action C87-1284A, Section C., paragraph 6 and Section D., paragraph 4. This information has also been submitted to the USEPA Region V RCRA Enforcement Branch and the Ohio EPA, Division of Solid and Hazardous Waste offices in Columbus and Twinsburg, Ohio.

Please address all inquiries in this matter to the undersigned.

Sincerely,

Edward J. Brosius

Edward J. Brosius
Assistant General Counsel
& Assistant Secretary

EJB/mlg
Enclosures

cc: C.A. Ruud

Amsted
INDUSTRIES

AMSTED INDUSTRIES
INCORPORATED
44TH FLOOR · BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8411
TELECOPIER (312) 819-8484

December 17, 1993

Director of the Ohio
Environmental Protection Agency
P.O. Box 1049
1800 Watermark Drive
Columbus, Ohio 43266-0149

RE: Letter for Chief Financial Officer
to Demonstrate Liability and Closure/Post Closure Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance, Ohio 44601
EPA I.D. #OHD 987090418 and

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D. # OHD 017497587

Dear Sir:

I am the chief financial officer of AMSTED Industries Incorporated; 205 North Michigan Avenue; Chicago, Illinois 60601. This letter is in support of the use of the financial test to demonstrate financial responsibility for liability coverage and closure care as specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code.

The firm identified above is the owner or operator of the following facilities for which liability coverage for both sudden and nonsudden accidental occurrences is being demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code:

Proposed Mount Athos Landfill
Griffin Pipe Products Company
Adams Street
P.O. Box 740
Lynchburg, VA 24505

American Steel Foundries
1001 East Broadway
Alliance, Ohio 44601
EPA I.D.# OHD 987090418

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D.# OHD 017497587

Diamond Chain Company
402 Kentucky Avenue
Indianapolis, IN 46207
EPA I.D.# IND 006067880

Griffin Pipe Products Company
Adams Street-Upper Basin
Lynchburg, VA 24501
EPA I.D.# VAD 065417008

Griffin Pipe Products Company
1100 West Front Street
Florence, NJ 08518
EPA I.D. # NJD 003951985

The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 through 3745-55-51 and 3745-66-40 through 3745-66-48 of the Administrative Code, liability coverage for both sudden and nonsudden accidental occurrences at the following facilities owned or operated by the following: The firm identified above is the direct or higher-tier parent corporation of the owner or operator: None

1. The firm identified above owns or operates the following facilities for which financial assurance for closure or post-closure care or liability coverage is demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of

the Administrative Code. The current closure and/or post-closure cost estimate covered by the test are shown for each facility:

Mount Athos Closure Cost	$ 1,900,000
Mount Athos Post-Closure Cost	$ 600,000
ASF Sebring Closure Cost	$ 875,554
ASF Sebring Post-Closure Cost	$ 619,200
ASF Alliance EAF Baghouse Area Closure Cost	$ 93,454
ASF Alliance Areas A & B Closure Cost	$ 157,380
DC Indianapolis Closure Cost	$ 53,578
GPP Lynchburg Closure Cost	$ 5,250

2. The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code, the closure and post-closure care or liability coverage of the following facilities owned or operated by the guaranteed party. The current cost estimates for the closure or post-closure so guaranteed are shown for each facility: None

3. The firm identified above is demonstrating financial assurance for the closure or post-closure care of the following facilities through the use of a test equivalent or substantially equivalent to the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 and 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates covered by such a test are shown for each facility: None

4. The firm identified above owns or operates the following hazardous waste management facilities for which financial assurance for closure or, if a disposal facility, post-closure care, is not demonstrated to the director through the financial test or any other financial assurance mechanisms specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates not covered by such financial assurance are shown for each facility: None

5. This firm is the owner or operator of the following UIC facilities for which financial assurance for plugging and abandonment is required under Chapter 3745-34 of the Administrative Code. The current closure cost estimates as required by Chapters 3745-34, 3745-55 and 3745-66 of the Administrative Code are shown for each facility: None

This firm is not required to file a Form 10K with the securities and exchange commission (SEC) for the latest fiscal year.

The fiscal year of this firm ends on September 30. The figures for the following items marked with an asterisk are derived from the firm's independently audited, year-end financial statements for the latest completed fiscal year, ended September 30, 1993.

Part B. Closure and Post-Closure Care and Liability Coverage

1.	Sum of current closure and post-closure cost estimates (total of all cost estimates listed above).	$ 4,304,416
2.	Amount of annual aggregate liability coverage to be demonstrated.	$ 8,000,000
3.	Sum of lines 1 and 2.	$ 12,304,416
*4.	Total liabilities (if any portion of your closure or post-closure cost estimates is included in your total liabilities, you may deduct that portion from this line and add that amount to lines 5 and 6).	$268,073,000
*5.	Tangible net worth.	$263,348,000
*6.	Net worth.	$275,383,000
*7.	Current assets.	$302,396,000
*8.	Current liabilities.	$114,787,000
9.	Net working capital (line 7 minus line 8).	$187,609,000
*10.	The sum of net income plus depreciation, depletion, and amortization.	$ 38,025,000
*11.	Total assets in U.S. (required only if less than 90% of assets are located in the U.S.).	Not Required
12.	Is line 5 at least $10 million?	YES
13.	Is line 5 at least 6 times line 3?	YES
14.	Is line 9 at least 6 times line 3?	YES

*15.	Are at least 90% of assets located in the U.S. If not, complete line 16.	YES
16.	Is line 11 at least 6 times line 3?	

NEED TWO OF THREE

17.	Is line 4 divided by line 6 less than 2.0?	YES
18.	Is line 10 divided by line 4 greater than 0.1?	YES
19.	Is line 7 divided by line 8 greater than 1.5?	YES

I hereby certify that the wording of this letter is identical to the wording specified in paragraph (G) of rule 3745-55-51 of the Administrative Code as such regulations were constituted on the date shown immediately below.

G K Walter
Gerald K. Walter
Vice President

12-17-93
Date

200 East Randolph Drive
Chicago, IL 60601

Telephone 312 565 1500

Price Waterhouse

REPORT OF INDEPENDENT ACCOUNTANTS

December 27, 1993

To the Board of Directors of
AMSTED Industries Incorporated

We have audited, in accordance with generally accepted auditing standards, the consolidated statement of financial position of AMSTED Industries Incorporated (AMSTED) and its subsidiaries as of September 30, 1993 and the related consolidated statements of results of operations and of cash flows for the fiscal year then ended, and have issued our report thereon dated October 20, 1993.

For purposes of this letter, we have compared the amounts of current assets ($302,396,000), current liabilities ($114,787,000), total liabilities ($268,073,000) and net worth ($275,383,000) included in the letter to the Ohio Environmental Protection Agency, dated December 17, 1993 and signed by Mr. G.K. Walter, AMSTED's Vice President and Chief Financial Officer, to the amounts included in the aforementioned financial statements. We have subtracted the amount of intangible assets from the amount of net worth included in the aforementioned financial statements and compared the difference to the amount indicated as tangible net worth ($263,348,000) in Mr. Walter's letter and found them to be in agreement. We added net income and depreciation, depletion and amortization included in the aforementioned financial statements and compared the total ($38,025,000) to the amount indicated as such in Mr. Walter's letter and found them to be in agreement. Finally, we calculated 90 percent of AMSTED's total consolidated assets included in the aforementioned financial statements and compared the amount calculated to total assets in the U.S. In connection with these procedures, nothing came to our attention that caused us to believe that the amounts of current assets, current liabilities, total liabilities, net worth, tangible net worth, and the sum of net income and depreciation, depletion and amortization as indicated in item 10 and the "yes" answer to item 15 included in the December 17, 1993 letter signed by Mr. Walter should be adjusted.

This report is intended solely for the information and use of the Board of Directors and management of AMSTED Industries Incorporated and the Ohio Environmental Protection Agency.

Price Waterhouse

AMSTED INDUSTRIES

INCORPORATED

44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482
TELECOPIER (312) 819-8484

July 29, 1993

RECEIVED
JUL 30 1993
OFFICE OF RCRA
WASTE MANAGEMENT DIV
EPA, REGION

CERTIFIED MAIL - RETURN RECEIPT REQUESTED
Chief, RCRA Enforcement Branch, 5HR-12
U.S. EPA Region V
77 W. Jackson Blvd.
Chicago, IL 60604
Attn: Kimberly Ogle

RE: Letter for Chief Financial Officer
to Demonstrate Liability Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance, Ohio 44601
EPA I.D. # OHD 987090418

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D. # OHD 017497587

Dear Ms. Ogle:

In reply to Ms. Tina Jennings of Ohio EPA letter of June 22, 1993 and further to my reply of July 19, 1993, copies enclosed, enclosed is a July 20, 1993 letter signed by Mr. Gerald K. Walter whereby AMSTED Industries Incorporated is demonstrating financial responsibility for liability coverage and closure and post-closure care for the subject owned facility. Also, enclosed is the certifying letter from Price Waterhouse, AMSTED's independent auditor. The printed copy of AMSTED's fiscal 1992 annual report was previously submitted.

This information is being submitted as required under the consent decree in U.S. v. AMSTED, civil action C87-1284A, Section C., paragraph 6 and Section D., paragraph 4. This information has also been submitted to the USEPA Office of Regional Counsel and the Ohio EPA, Division of Solid and Hazardous Waste offices in Columbus and Twinsburg, Ohio.

Please address all inquiries in this matter to the undersigned.

Sincerely,

Edward J Brosius

Edward J. Brosius
Assistant General Counsel
& Assistant Secretary

EJB/kda
Enclosure

AMSTED INDUSTRIES
INCORPORATED

44TH FLOOR · BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482
TELECOPIER (312) 819-8484

July 20, 1993

Director of the Ohio
Environmental Protection Agency
P.O. Box 1049
1800 Watermark Drive
Columbus, Ohio 43266-0149

RE: Letter for Chief Financial Officer
to Demonstrate Liability Coverage
American Steel Foundries
Division of AMSTED Industries Incorporated
1001 East Broadway
Alliance, Ohio 44601
EPA I.D. #OHD 987090418 and

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D. # OHD 017497587

Dear Sir:

I am the chief financial officer of AMSTED Industries Incorporated; 205 North Michigan Avenue; Chicago, Illinois 60601. This letter is in support of the use of the financial test to demonstrate financial responsibility for liability coverage and closure care as specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code.

The firm identified above is the owner or operator of the following facilities for which liability coverage for both sudden and nonsudden accidental occurrences is being demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code:

American Steel Foundries
1001 East Broadway
Alliance, Ohio 44601
EPA I.D.# OHD 987090418

American Steel Foundries Sebring Landfill
Lake Park Boulevard and Heacock Road
Smith Township, Mahoning County, Ohio
EPA I.D.# OHD 017497587

Diamond Chain Company
402 Kentucky Avenue
Indianapolis, IN 46207
EPA I.D.# IND 006067880

Griffin Pipe Products Company
Adams Street-Upper Basin
Lynchburg, VA 24501
EPA I.D.# VAD 065417008

Griffin Pipe Products Company
1100 West Front Street
Florence, NJ 08518
EPA I.D. # NJD 003951985

The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 through 3745-55-51 and 3745-66-40 through 3745-66-48 of the Administrative Code, liability coverage for both sudden and nonsudden accidental occurrences at the following facilities owned or operated by the following: The firm identified above is the direct or higher-tier parent corporation of the owner or operator: None

1. The firm identified above owns or operates the following facilities for which financial assurance for closure or post-closure care or liability coverage is demonstrated through the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimate covered by the test are shown for each facility:

ASF Sebring Closure Cost	$ 848,405.
Post-Closure Cost	$ 600,000.
ASF Alliance Closure Cost	$ 90,556.

DC Indianapolis Closure Cost	$ 50,000.
GPP Lynchburg Closure Cost	$ 5,000.

2. The firm identified above guarantees, through the guarantee specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code, the closure and post-closure care or liability coverage of the following facilities owned or operated by the guaranteed party. The current cost estimates for the closure or post-closure so guaranteed are shown for each facility: None

3. The firm identified above is demonstrating financial assurance for the closure or post-closure care of the following facilities through the use of a test equivalent or substantially equivalent to the financial test specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 and 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates covered by such a test are shown for each facility: None

4. The firm identified above owns or operates the following hazardous waste management facilities for which financial assurance for closure or, if a disposal facility, post-closure care, is not demonstrated to the director through the financial test or any other financial assurance mechanisms specified in rules 3745-55-40 to 3745-55-51 and 3745-66-40 to 3745-66-48 of the Administrative Code. The current closure and/or post-closure cost estimates not covered by such financial assurance are shown for each facility: None

5. This firm is the owner or operator of the following UIC facilities for which financial assurance for plugging and abandonment is required under Chapter 3745-34 of the Administrative Code. The current closure cost estimates as required by Chapters 3745-34, 3745-55 and 3745-66 of the Administrative Code are shown for each facility: None

This firm is not required to file a Form 10K with the securities and exchange commission (SEC) for the latest fiscal year.

The fiscal year of this firm ends on September 30. The figures for the following items marked with an asterisk are derived from the firm's independently audited, year-end financial statements for the latest completed fiscal year, ended September 30, 1992.

Part B. Closure and Post-Closure Care and Liability Coverage

1. Sum of current closure and post-closure cost estimates (total of all cost estimates listed above). $1,593,961

2. Amount of annual aggregate liability coverage to be demonstrated.	$8,000,000
3. Sum of lines 1 and 2.	$9,593,961
*4. Total liabilities (if any portion of your closure or post-closure cost estimates is included in your total liabilities, you may deduct that portion from this line and add that amount to lines 5 and 6).	$271,495,000
*5. Tangible net worth.	$237,413,000
*6. Net worth.	$250,622,000
*7. Current assets.	$285,570,000
*8. Current liabilities.	$117,812,000
9. Net working capital (line 7 minus line 8).	$167,758,000
*10. The sum of net income plus depreciation, depletion, and amortization.	$ 34,545,000
*11. Total assets in U.S. (required only if less than 90% of assets are located in the U.S.).	$458,563,000
12. Is line 5 at least $10 million?	YES
13. Is line 5 at least 6 times line 3?	YES
14. Is line 9 at least 6 times line 3?	YES
*15. Are at least 90% of assets located in the U.S. If not, complete line 16.	NO
16. Is line 11 at least 6 times line 3?	YES

<u>NEED TWO OF THREE</u>

17. Is line 4 divided by line 6 less than 2.0? <u>YES</u>

18. Is line 10 divided by line 4 greater than 0.1? <u>YES</u>

19. Is line 7 divided by line 8 greater than 1.5? <u>YES</u>

I hereby certify that the wording of this letter is identical to the wording specified in paragraph (G) of rule 3745-55-51 of the Administrative Code as such regulations were constituted on the date shown immediately below.

GK Walter

Gerald K. Walter
Vice President

7-20-93

Date

200 East Randolph Drive
Chicago, IL 60601

Telephone 312 565 1500

Price Waterhouse

REPORT OF INDEPENDENT ACCOUNTANTS

July 27, 1993

To the Board of Directors of
AMSTED Industries Incorporated

We have audited, in accordance with generally accepted auditing standards, the consolidated statement of financial position of AMSTED Industries Incorporated (AMSTED) and its subsidiaries as of September 30, 1992 and the related consolidated statements of results of operations and of cash flows for the fiscal year then ended, and have issued our report thereon dated October 21, 1992.

For purposes of this letter, we have compared the amounts of current assets ($285,570,000), current liabilities ($117,812,000), total liabilities ($271,495,000), net worth ($250,622,000) and total assets in the U.S. ($458,563,000) included in the letter to the Ohio Environmental Protection Agency, dated July 20, 1993 and signed by Mr. G.K. Walter, AMSTED's Vice President and Chief Financial Officer, to the amounts included in the aforementioned financial statements. We have subtracted the amount of intangible assets from the amount of net worth and compared the difference to the amount indicated as tangible net worth ($237,413,000) in Mr. Walter's letter and found them to be in agreement. We added net income and depreciation, depletion and amortization and compared the total ($34,545,000) to the amount indicated as such in Mr. Walter's letter and found them to be in agreement. Finally, we calculated 90 percent of AMSTED's total consolidated assets included in the aforementioned financial statements and compared the amount calculated to total assets in the U.S. In connection with these procedures, nothing came to our attention that caused us to believe that the amounts of current assets, current liabilities, total liabilities, net worth, total assets in the U.S., tangible net worth, and the sum of net income and depreciation, depletion and amortization as indicated in item 10 and the "no" answer to item 15 included in the July 20, 1993 letter signed by Mr. Walter should be adjusted.

This report is intended solely for the information and use of the Board of Directors and management of AMSTED Industries Incorporated and the Ohio Environmental Protection Agency.

Price Waterhouse

ENV — FINAN — RESP —

AMSTED INDUSTRIES

INCORPORATED

44TH FLOOR - BOULEVARD TOWERS SOUTH
205 NORTH MICHIGAN AVENUE · CHICAGO, ILLINOIS · 60601

LAW DEPARTMENT

DIRECT DIAL NUMBER
(312) 819-8482

TELECOPIER (312) 819-8484

July 19, 1993

Tina Jennings
Compliance Monitoring and Enforcement Section
Division of Hazardous Waste Management
Ohio EPA
PO Box 1049, 1800 Watermark Drive
Columbus, Ohio 43266-0149

Re: American Steel Foundries
Sebring Landfill
OHD017497587

Dear Ms. Jennings:

This is in reply to your letter of June 22, 1993 to Mr. Gerald K. Walter.

The December 31, 1992 letter from Mr. Walter demonstrating financial assurance for closure/post closure and liability of the subject facility was based on closure/post closure cost estimates current at the time of the letter. Subsequently, when RMT, Inc. completed the closure plan for the subject facility in the January 1993 document, updated closure cost estimates were prepared. Copies of letters from RMT dated July 14 and 19, 1993 and a May 1993 Table 1 reflecting the updated closure and post closure cost estimates are enclosed.

An updated financial responsibility letter is being prepared and will be forwarded to you shortly.

Please address any questions to the undersigned.

Sincerely,

Edward J. Brosius
Assistant General Counsel
& Assistant Secretary

cc: G.K. Walter
C. Ruud

Amsted

RMT INC.

999 Plaza Drive
Suite 100
Schaumburg, IL 60173
Phone: 708-995-1500
FAX: 708-995-1900

to EJB. as info

cc: VTH.

July 14, 1993

cf/R 7/16/93

RECEIVED
JUL 16 1993
LAW DEPT.

Mr. Chuck Ruud
American Steel Foundries
10 South Riverside Plaza
10th Floor
Chicago, IL 60606

Dear Chuck,

As you informed us by telephone yesterday, a discrepancy has been noted by the Ohio EPA in the estimated closure costs for the Alliance facility landfill between Section 12 and Appendix L of the Landfill Closure Plan ($934,000.00 vs $848,405.00, respectively).

Appendix L is a detailed listing of the estimated closure costs. As you will note on page 4, item #157 is a 10% contingency factor. In the original draft, RMT had added the 10% contingency to the cumulative sub-total of $848,405.00. The new total, $934,000.00, was listed as the estimated closure cost in Section 12 of the Landfill Closure Plan.

During final client review, American Steel Foundries opted to remove the 10% contingency factor from the total (please note that line #157 in Appendix L has a value of $0.00). However, the old total of $934,000.00 in Section 12 was not changed to reflect the latest revision. This number should be $848,405.00.

Please call if you have any further questions.

Very truly yours,

Mike Slattery

Mike Slattery
Program Manager

RMT INC

999 Plaza Drive
Suite 100
Schaumburg, IL 60173
Phone: 708-995-1500
FAX: 708-995-1900

July 19, 1993

Mr. Chuck Ruud
American Steel Foundries
10 South Riverside Plaza
10th Floor
Chicago, Illinois 60606

Dear Mr. Ruud,

Per your request, RMT has reviewed the post-closure costs in the Landfill Closure Plan for American Steel Foundries, Alliance, Ohio. There is no discrepancy between the post-closure costs listed in Section 12 of the Landfill Closure Plan and Appendix L. Appendix L lists the total cost for years 1 through 30 at $600,400.00. Section 12 lists the post-closure cost for year 1 at $56,000 and the remaining years 2 through 30, at $544,000.00. The total in Section 12, $600,000, agrees with Appendix L.

Please call if you have any further questions.

Very truly yours,

Mary Lynn Hall

Mary Lynn Hall
Project Manager

REVISED: MAY 1993

TABLE 1
CLOSURE COST ESTIMATE
ASF - BROADWAY STREET FACILITY, ALLIANCE, OHIO

UNIT OF MAJOR ACTIVITY	TASK	UNIT	QUANTITY	UNIT COST	TOTAL COST*
CONTRACTOR IMPLEMENTATION					
Mobilization	—	Lump Sum	1	$1,000	$1,000
Labor and Equipment	Excavation, decontamination and backfilling beneath the baghouse	Days	5	$2,500	$12,500
Decontamination Pad Construction	Construction and dismantling of the decontamination pad	Lump Sum	1	$2,500	$2,500
Concrete Pad Construction	Concrete pad and curbing construction	Lump Sum	1	$10,000	$10,000
RESIDUALS MANAGEMENT					
Solid Hazardous Waste	Off-site transport and treatment of solid wastes	Cubic Yards	90	$300	$27,000
Rinsate	Off-site transport and treatment of rinsate	Gallons	110	$0.40	$44.00
DOCUMENTATION ACTIVITIES					
On-Site Engineering Documentation	—	Lump Sum	1	$5,000	$5,000
Soil Sampling	—	Lump Sum	1	$6,000*	$6,000*
Soil Analysis	—	Sample	38*	$150*	$5,700*
Rinsate Analysis	—	Sample	2	$2,000	$4,000
Documentation Report	—	Lump Sum	1	$5,000	$5,000
CLOSURE COST					$78,744*
Contingency	—	Lump Sum	1	15%	$11,812*
TOTAL CLOSURE COSTS					$90,556*

P:\DATA\PROJECTS\ASF\COST.EST

* = revised May 1993

OhioEPA

State of Ohio Environmental Protection Agency

P.O. Box 1049, 1800 WaterMark Dr.
Columbus, Ohio 43266-0149

RECEIVED
OCT 04 1989
OFFICE OF RCRA
WASTE MANAGEMENT DIVISION
EPA, REGION V

Richard F. Celeste
Governor

September 27, 1989

Re: American Steel Foundries
OHD017497587
Financial Assurance

Paul Limbach
American Steel Foundries
1001 East Broadway
Alliance, Ohio 44601

Dear Mr. Limbach:

On September 26, 1989, I conducted an annual financial record review for the American Steel Foundries facility referenced above. I evaluated its compliance with the financial assurance requirements set forth in Ohio Administrative Code (OAC) rules 3745-66-42 through 3745-66-47. Under these rules, American Steel Foundries must have and maintain cost estimates for closure and post-closure facility care, financial assurance for closure and post-closure care, and liability coverage for sudden and nonsudden accidental occurrences.

As a result of my review, I find that American Steel Foundries has not established such financial assurance and remains in violation of OAC rules 3745-66-42 through 3745-66-47.

I note that these issues and others are currently the subject of litigation between U.S. EPA and Amsted Industries, Inc. d/b/a American Steel Foundries.

Please submit documentation within thirty (30) days of the date of this letter correcting the above violations. If you have questions, please call me at (614) 644-2944.

Sincerely,

Carolyn J. Reierson

Carolyn J. Reierson
RCRA Enforcement Section
Division of Solid and Hazardous Waste Management

CJR/kah
Psl.27

cc: Mike Savage, DSHWM
Kevin Bonzo, NEDO
Catherine McCord, U.S. EPA, Region V.